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THE STRUCTURE AND ORIGIN OF THE BANDED HEMATITE JASPERS OF SINGHBHUM, INDIA.

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ABSTRACT.

The Precambrian Banded Hematite Jaspers of the iron ore field of Singhbhum and Orissa, India, are less altered than many of their equivalents in other parts of the world. They show the usual predominance of martite in the iron oxide bands, and the presence of rhomb structures, and they are leached to slump and powdery ores. Folding on a small scale has produced some fracturing and some puckering without fractures. The latter type of folding occurred before final consolidation of the beds.

The jasper bands commonly show a polygonal pattern, with fine clear silica boundaries enclosing areas filled with hematite "dust," formed by the gradual shrinkage of a colloidal silica-iron oxide gel. Minute spherulites abound, with cores of dense iron oxide, and surrounding clear silica, showing the usual black cross between crossed nicols. These spherulites tend to occur in layers parallel to the banding, giving the appearance of lines or chains in sections across the banding. Similar structures elsewhere have previously not been recognized as spherulites, but have been thought to be possibly microorganisms. Associated with the spherulites are shrinkage cracks.

The origin of the banded hematite jaspers is discussed in reference to these textures.

THE Precambrian Banded Hematite Jaspers of the district of Singhbhum, South Bihar, which extend into the former states of Keonjhar and Bonai in the Province of Orissa, have been previously termed Banded Hematite Quartzites, but they are jaspers, and should be so designated. They are identical in appearance with the "Calico rock" of South Africa, and resemble very closely some of the banded jaspillites of the Vermilion Range of the Lake Superior district. They are obviously of similar origin to the itabirites of Brazil, but the silica in the itabirites is recrystallized. Some of the similar Australian rocks have also been partially recrystallized, as also occurrences in Mauretania and elsewhere. We have seen samples from Labrador that appeared to be jaspers. These beds are unique, not only in their widespread similarity, but also on account of their association with very rich deposits of iron ore, which in their purity and quantity probably exceed the sum total of all later sedimentary iron ore deposits.

The conditions under which these unique rocks were produced have been frequently discussed. As Leith (12)[1] has emphasized, although they can be imitated on a laboratory scale it is difficult to explain why they were repeated on such a huge scale in Precambrian times in such widely dispersed areas.

The rocks we propose to describe have been investigated mainly by H. C. Jones and J. A. Dunn, both formerly of the Geological Survey of India, and the authors. Dunn (3) stated that these beds are essentially tuffs and sediments altered after deposition by replacement on a large scale. He says, "the immediate neighborhood of the larger iron ore deposits in Singhbhum provides little evidence to support any theory of their origin. A wider survey over

FIG. 1. Banded hematite-jasper, showing plastic deformation in mainly jasper bands, between competent layers. × 0.4.

several thousand miles of country demonstrates that the associated banded quartzites are not sedimentary, but are due to secondary silicification of material now represented by ferruginous, chloritic, or carbon shales or phyllites, many of which originated as tuffs. Other theories advanced to date are untenable in Singhbhum." Later, in his Memoir on this area (4) he expressed similar views, and did not consider the banding to be anything unusual, adding that it "is no more striking than the fine banding in, say, a normal shale."

In the field the general appearance of the banded jasper beds is that of a hard, platy, brick-red jasper rock traversed by bands of steely gray hematite, which lie more or less parallel to the bedding. The bands may vary from several inches in width down to microscopic size. In hand specimens the banding may show an even parallel arrangement, but more often the bands are seen to thin out or thicken locally, and to taper out lenticularly along the bedding. Commonly the banding is traversed almost perpendicularly by fine to medium sized quartz "veins." These veins may lie along planes of normal

[1] Numbers in parentheses refer to Bibliography at end of paper.

faulting with a shift or throw of the banding on one side of the "fault vein." As will be seen in our description of their microscopic characters the quartz veins represent an infilling of spaces by relatively coarse crystalline quartz rather than replacement of jasper material.

In some areas these banded jaspers have been subjected to considerable pressure, and the rocks have been folded and contorted in remarkable fashion. Although previous writers have described these folds it does not appear that previously any distinction has been made between the two types, (a) plastic deformation, and (b) shatter folding. In the former type (Fig. 1) the rock is puckered or squeezed without any serious amount of fracturing, but with the production of drag folds, knots, and lenses in both the hematite and the

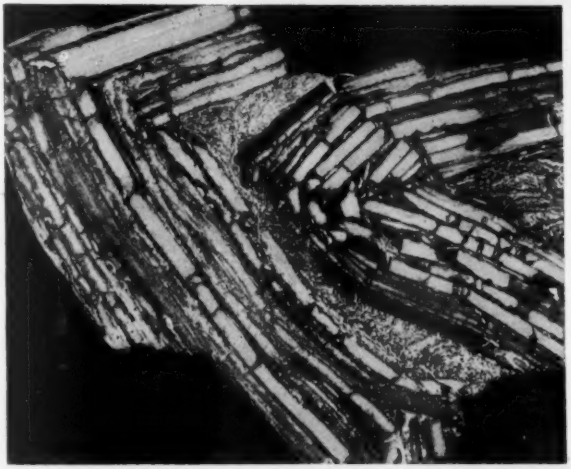

FIG. 2. Small fractured "anticlinal" fold. Polished surface. × 1.

siliceous bands. In the latter type the hard siliceous bands are fractured, both on a large scale and in minute detail, with the production of miniature faults. In many cases these small faults show a lateral shift at the junction with a hematite band, the latter being bent at the junction, indicating that at these points the hematite has yielded to pressure, whereas the jasper band has been hard and resistant. The hand specimen seen in Figure 2, for example, shows a trough or anticline, with the jasper bands fractured into small plates along the folds, with some of the iron oxide squeezed into the resultant cracks, and into the cavities in the anticlinal apices.

Dunn (5, p. 337) says, "it is difficult to appreciate how such minute folds could have been imparted to such a competent rock. However, its finely laminated character and its high hematite content is the probable explanation, for under pressure, the ferruginous laminae would readily yield, the thin silica layers following suit."

If this were so it should have happened generally, whereas in many cases fracturing and not puckering has occurred. In these cases some of the iron oxide has "flowed" along the crevices as mentioned above, but the silica and the bulk of the hematite have remained rigidly in their original bedded shape, though broken up into small sections. The layers have not, in these fractured beds, thinned and thickened, nor have they become lenticular, nor formed dragged knots as has happened in the puckered beds. In the latter, by con-

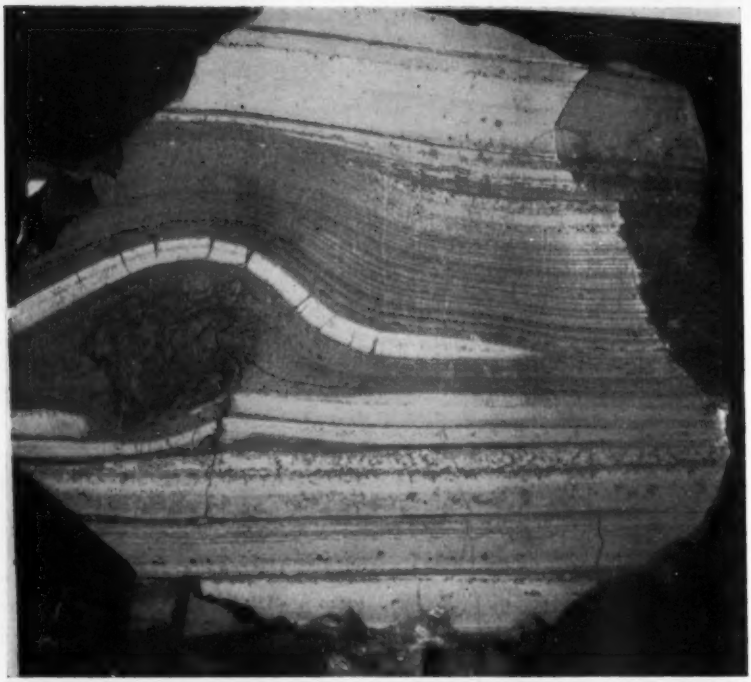

FIG. 3. Polished hand specimen of Banded Hematite Jasper, showing puckering of hematite layer. × 1.

trast, few fractures have been formed. The individual bands swell out, or are drawn into lenticles. An iron oxide lens, with paper-thin silica bands included, may have been rolled over and knotted as in Figure 3. In our view puckering of this nature could only take place while the beds were soft and plastic, and might have been caused by currents, or by slight movements of the sedimentary floor, coupled possibly with thixotropic changes, i.e., gel-sol changes in colloidal sedimentary layers of differing composition and density.

In brief, the two types of distortion, puckering and fracturing, have oc-

curred at different times, the former while the rock was still in an unconsolidated gel condition, the latter after it had become hard and solid.

From the foregoing it will be obvious that we do not agree at all with Dunn's secondary silicification theory, nor do we see any necessity to go to localities far away from these banded rocks to seek their origin. Such a course carries the obvious risk that one's correlations or assumptions of similarity may be mistaken, and indeed, after we had pointed out the incorrect placing of the "basal" conglomerate in the Geological Survey publications (which was originally based on correlations farther afield), Dunn (5) entirely revised the succession in this area.

We do not propose to summarize the many descriptions and suggested explanations that have been published on rocks of this type. Miles (14) has quoted a number of them. In describing the microscopic features we have found in the banded hematite jaspers of our area we do not assume that similar structures will be found elsewhere, but we think it probable, from the close similarity in general appearance, that a detailed examination will reveal similar structures in banded jaspers of other areas, especially if attention is directed to those showing regular banding and no metamorphism. Indeed, in the very few slides we have been able to examine from the Marquette, Vermilion, and the Labrador areas we have found indications of this.

MICROSCOPIC CHARACTERS OF THE BANDED JASPERS.

Dark Ferruginous Bands.

Under the microscope the dark gray-black bands, which appear in hand specimens to consist almost entirely of iron oxide material, are seen to contain numerous fine parallel bands, stringers or lenticles of clear crystalline silica. Even the darkest and most dense bands show, here and there, stringers or cavities filled with this material.

Martite.—By reflected light the iron oxide has a steely-gray color with red or brown stains or mottling. By transmitted light the greater part of the ferruginous material is opaque. Along the junction with the clear crystalline silica these opaque bands show in sharp silhouette, generally with serrated edges made up of small octahedra. The octahedral form can be more clearly made out where occasional isolated crystals occur within the clear silica. It is best seen in weathered hand specimens where the colloidal silica has been removed, leaving a loose silica matrix in which, on a fractured surface, the small octahedral crystals stand out in relief.

These octahedral crystals, and aggregates of them in parallel growth, are also found to constitute the bulk of the material of the powdery ore ("blue dust") met with in mining the iron ore deposits. This "blue dust" represents, in all probability, the residues from intensive leaching of the banded hematite jaspers, practically all the silica having been removed by meteoric action, leaving a blue-gray powder of almost pure hematite. A microscopic examination of this dust reveals the presence of abundant octahedra, generally in the form of aggregates in parallel growth. A few hand-picked crystal aggregates from this "blue dust" can be seen in Figure 4, as photographed by reflected light.

The individual octahedra are remarkably uniform in size, rarely exceeding 0.2 mm, but with parallel aggregates up to 2 mm in length. A considerable proportion of this dust, on screening, is found to pass a 100-mesh screen. This portion is non-magnetic. Of the remainder, which mainly lies between

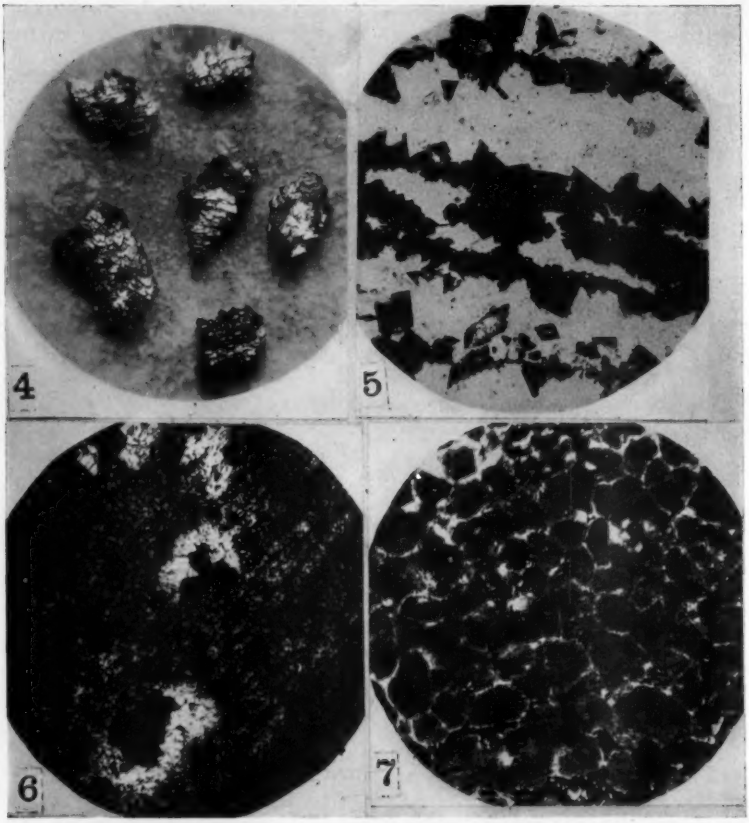

FIG. 4. Hand-picked aggregates of martite crystals from the "Blue-dust," showing parallel growths, by reflected light. × 17.

FIG. 5. Section across banded jasper showing bands of altered siderite, and of martite. Ordinary light. × 25.

FIG. 6. Section of ferruginous banded jasper showing quartz blades growing out perpendicularly from the surface of martite crystals. x-nicols. × 25.

FIG. 7. Section of red part of a jasper band showing a mosaic or polygonal texture in the otherwise uniform jasper material. Ordinary light. × 50.

30 and 80 mesh, about 5 percent is picked up by an ordinary hand magnet. An average sample of the "blue dust" gave the following analysis:

Fe_2O_3	99.05%
FeO	0.56%
Al_2O_3	0.40%
S	0.012%

It is evident that by far the greater part of the ferruginous material of these banded jaspers, and of the associated iron ores, has at one time existed as magnetite, now altered to hematite (or martite).

Although most of the iron oxide of the dark gray bands in the banded jaspers consists of this opaque martitic material one also sees, in sections under the microscope, dark brown-red translucent grains and patches of hematite. Bladed crystals of dark red hematite also occur projecting into the silica field from the martite material, and in the silica-filled cavities.

Altered Siderite.—In places along the silica-martite junctions, or as separate bands or stringers, one also sees rhombic sections of a translucent dark brown material suggesting the original presence of siderite, now largely altered to hematite. A number of these bands can be seen in Figure 5, two of them enclosing a band of martite crystal aggregates.

The quartz stringers or lenticles which border the dense iron oxide bands, or are enclosed by them, are much more coarsely crystalline than the silica of the intervening red jasper bands, and are, as a rule, clear and free of iron oxide. The texture is generally bladed, with the quartz blades growing out perpendicularly from the crystal faces of the martite, as may be seen between crossed nicols in Figure 6.

Red Jasper Bands.

Under the microscope, the red color of the jasper bands is seen to be due to hematite "dust" or flakes in a finely disseminated state, the darker or lighter bands and lenticles indicating a greater or lesser degree of concentration of this hematite. The groundmass consists of finely crystalline silica.

Polygonal Texture.—In many cases the jasper groundmass shows a mosaic pattern as in Figure 7, with sharp polygonal boundaries of finely crystalline clear silica enclosing darker areas spattered with hematite dust. Individually these darker areas tend to extinguish uniformly between crossed nicols. A transition from the ordinary to the mosaic type of groundmass in a jasper band is shown in Figure 8.

Occasionally, where the uniformity of the banding is interrupted by lenticles or "blebs" richer in disseminated iron oxide, as in Figure 9, the polygonal texture is shown up much more clearly in the darker lenticles, the appearance being somewhat suggestive of a micro-septarian texture.

As will be seen later, when discussing the micro-spherulitic textures in these banded jaspers, there can be little doubt that these polygonal textures, with clear, sharp borders of iron-free silica, were formed by the gradual shrinkage of a colloidal silica-iron oxide gel, the boundaries having been filled in later with relatively pure silica.

Rhomb Pseudomorphs, or "Ghost rhombs."—Further evidence of the former presence of siderite or other carbonate minerals in these banded jaspers, mentioned above, is the persistant occurrence of rhombic pseudomorphs scattered through the silica groundmass of the jasper field. These have been referred to by us in a previous paper (16) and they have been described in the banded hematite rocks of other areas. In sections under the microscope they

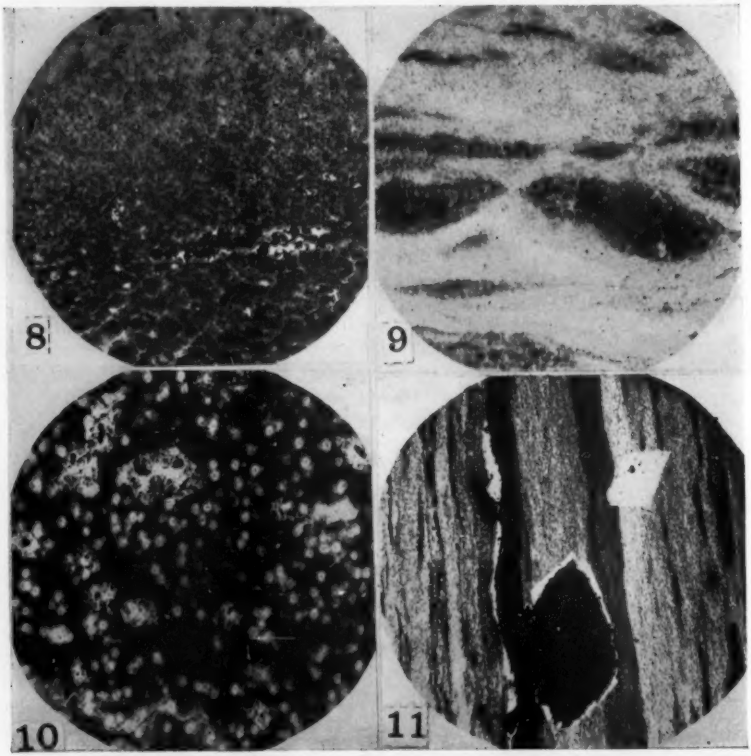

FIG. 8. Section showing a transition from the ordinary to the mosaic type of texture in the jasper field. Ordinary light. × 28.

FIG. 9. Section of non-uniform jasper band showing darker lenticles, with septaria-like shrinkage cracks in the darker lenticles. Ordinary light. × 58.

FIG. 10. Section of jasper band showing rhomb pseudomorphs. Ordinary light. × 60.

FIG. 11. Section of banded jasper showing occluded rhombs of carbonate material now altered to limonite and silica. The larger rhomb is mainly limonite with a fringe of silica crystals grown perpendicular to the rhomb surface. The smaller crystal is mainly silica of replacement. Ordinary light. × 30.

appear as geometrical rhombic forms containing more coarsely crystalline silica than the surrounding groundmass, or with a different proportion or arrangement of the hematite material. A number of these pseudomorphs are shown in Figure 10. The silica within these rhombs appears to be much more vulnerable to weathering than that of the surrounding field, since they show up as rhomb-shaped cavities or pits on a weathered surface. Their size lies roughly within the same range as that of the martite crystals.

Occasionally isolated rhombs are found to contain only hematite or limonite, and appear to have been deposited or to have grown within the sedimentary colloid during deposition without disturbance of the micro-banding (Fig. 11). Usually such rhombs show a margin of clear silica, as with the martite crystals and aggregates, the quartz again growing out as blades perpendicular to the rhomb faces. Miles (14) has described similar marginal growths in the jaspillites of Western Australia, and considers them to be "pressure fringes." They appear to us to be normal crystallizations perpendicular to the initiating surfaces.

More rarely one finds in these jasper bands rounded or incomplete rhombic forms as seen in Figure 12. These appear to be skeletal crystal growths formed within the sedimentary colloid, the darker bands of the sediment passing without interruption through the crystal.

In order to ascertain whether the chemical composition gave any evidence of carbonate residues in these rhomb-bearing jasper bands, a complete analysis was carried out of a typical sample of banded jasper containing "ghost" rhombs, martite, and the spherulitic structures to be described later. This analysis is given below.

Moisture below 105° C.	0.08%
Moisture above 105° C.	1.79
CO_2	0.66
Fe_2O_3	30.64
FeO	3.23
SiO_2	61.42
Al_2O_3	0.10
CaO	0.48
MgO	0.20
Alkalies as K_2O	0.94
	99.54%

It will be noted that the rock contains 0.66 percent of carbon dioxide, which corresponds to 1.64 percent $FeCO_3$ or 1.5 percent $CaCO_3$. The ferrous iron content is very much higher, proportionally, than in the associated dense iron ore bodies. The very low alumina content is typical of these beds.

Although fresh carbonate material appears to be almost absent from these banded jaspers, as seen in section under the microscope, unaltered siderite rhombs of similar form and size have been observed in many of the associated gray-green cherty bands. Fresh siderite rhombs of this type are shown in Figure 13.

Absence of Detrital Minerals.—In the large number of sections of these banded jaspers examined, no evidence was seen of detrital minerals, or of other compounds than silica and oxides of iron with perhaps some carbonate. This

was further verified by acid digestion, elutriation, and microscopic examination of powdered material from the iron ores, the banded jaspers, and the associated shales or tuffs. In no case were other minerals than the above found in the residues.

Spherulitic Structures.—Scattered throughout the jasper bands one finds small concretionary bodies, which in their best developed form have a radial or spherulitic structure; they appear to favor the darker red jasper bands,

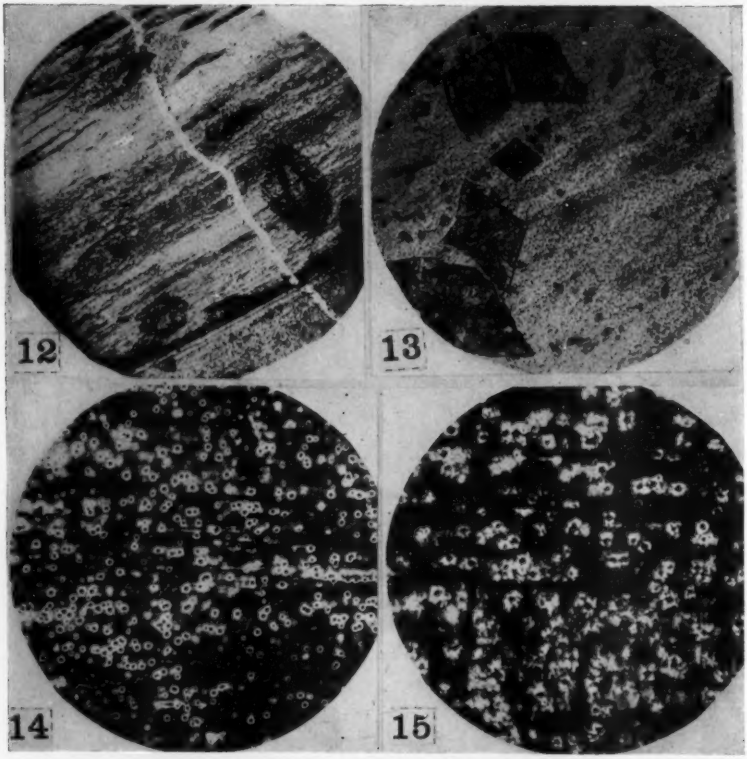

FIG. 12. Section of banded jasper showing ghost rhombs grown in the colloidal sediment, with the banding passing through the crystal. Ordinary light. × 34.

FIG. 13. Section of gray jasper showing fresh siderite rhombs. Ordinary light. × 34.

FIG. 14. Section across a red part of the jasper bands showing the spherulitic structures. Ordinary light. × 25.

FIG. 15. Section across a red part of a jasper band showing spherulitic structures. x-nicols. × 50.

especially those with sharp even banding, and to be absent or scarce in the pale varieties. Where well developed they consist of a central core or spherule of dense iron oxide with a surrounding clear "halo" of crystalline silica, as can be seen in Figure 14. Under crossed nicols this silica is seen to consist of quartz blades having a roughly radial arrangement. Figure 15 shows the appearance under crossed nicols. Generally the central core consists (as seen under high magnification) of an aggregate of minute grains or crystals of opaque oxide, but occasionally a single crystal of rhombic or octahedral form occupies the center, as may be seen in Figure 16, which is a portion more highly magnified. In places, these spherulitic concretions are scattered more or less evenly throughout the jasper field, but it is more common for them to lie in lines or chains roughly parallel to the banding of the jasper, in many cases joining up in pairs or multiples. Where the micro-banding of the jasper is not particularly marked the chains of spherulites may have a random direction.

As one approaches a region or band in the jasper with denser iron oxide the spherulites tend to become smaller and less prolific, whereas in the less ferruginous areas they tend to become larger, and to join up or run together, but with smaller central opaque cores until in the pale jaspers, low in iron oxide, they are absent altogether.

This would suggest that there has been an optimum condition for their formation in respect to the iron oxide–silica ratio. But it must be remembered that the decrease in size and abundance of the spherulites in the denser areas may be in part only apparent. The average diameter of these spherulites is about 0.05 mm, whereas the thickness of the microscope sections containing them is about 0.025 to 0.05 mm, so that even with a median section of a spherulite there must always be some groundmass material directly above or below the spherulite. This tends to cut down the illumination in the denser fields and so reduce the apparent diameter and abundance of the spherulites.

In addition to the tendency to string together along the direction of banding there is a suggestion of ovality in that direction, especially where they have grown in the denser areas, some of the spherulites being like small oölitic bodies. Another variation of these spherulites has larger central opaque cores with a narrow quartz rim, and in other cases the core is absent altogether, the concretion consisting only of a granular quartz spherule. Again one finds all gradations from true cored spherulites as described above down to scattered opaque granules with a mere suggestion of siliceous "halo."

In order better to examine the arrangement of the quartz blades within these spherulitic structures, uncovered sections were leached with warm strong hydrochloric acid containing stannous chloride. This treatment was found to remove the iron oxide of the central cores, but had very little effect on the hematite dust of the jasper field. The appearance of one of these leached sections as seen in ordinary light is shown in Figure 17 and under crossed nicols in Figure 18. Here the crude "black crosses" due to the roughly radial arrangement of the quartz blades is evident.

The removal of the opaque iron oxide core with resultant central cavity would have led one to expect non-illuminated centers to these leached spheru-

lites under crossed nicols. The absence of such dark centers is undoubtedly due to the fact referred to above, that with a median section of a spherulite (the optimum condition for seeing a good black cross in ordinary circum-

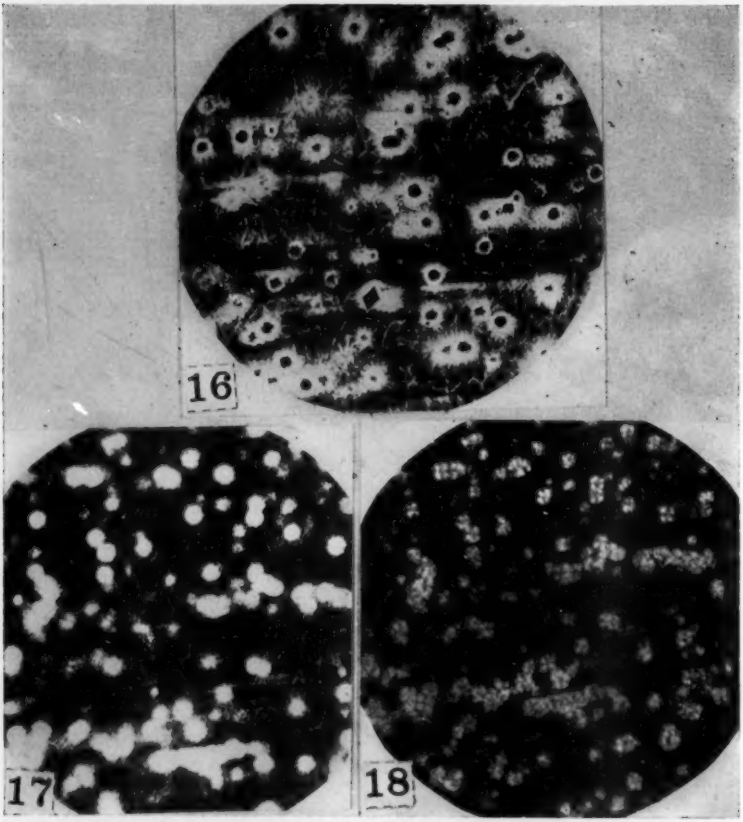

FIG. 16. Same section as Fig. 14, more highly magnified. Shows some rhomb centers to the spherulites, and prominent polygonal shrinkage cracks partly determined by the spherulites. Ordinary light. × 78.

FIG. 17. Spherulitic jasper section leached with warm hydrochloric acid and stannous chloride to remove hematite, leaving clear silica spherules. The disseminated hematite of the jasper groundmass is unaffected. Ordinary light. × 78.

FIG. 18. Same section as Figure 17 between crossed nicols. Shows crude black crosses in the silica spherules indicating roughly radial arrangement of the silica crystallites. Note that removal of the hematite cores has not left a black center. The section is not sufficiently thin to avoid some radial silica above or below the hollow center. × 65.

stances) more than half of a complete spherulite lies in the section. This may also in part account for the imperfection of the black crosses, since the quartz blades are not all parallel to the section plane.

Associated Shrinkage Cracks.—Associated with these spherulites are numerous "shrinkage cracks" somewhat similar to those described above in the uniform jasper field. These are best seen in the highly magnified section of Figure 16, and in the leached section of Figure 17. They have a roughly polygonal arrangement as previously described, but in this case the position of the cracks has obviously been determined by the spherulites, many of the latter being more or less completely enclosed by shrinkage cracks. These cracks are filled with clear, finely crystalline silica, and show up faintly in polarized light as can be seen in Figures 15 and 18.

It is difficult to believe that the above structures, with their accompanying shrinkage cracks, have been formed by rearrangement or replacement after the complete consolidation of the sediments. In our view they have been formed during the dehydration and consolidation of the original silica-iron oxide colloidal sediments. S. C. Bradford (1), working on the Leisegang phenomenon of banded structures in gels, has shown that the character of the banding is profoundly modified by the condition of the precipitate formed in the bands. If the precipitate is fine-grained, or if spherulitic, i.e. if it has a large surface area, the banding is sharp and clear, but if the precipitate is coarsely crystalline with a relatively small surface area, the banding tends to disappear. By suitably adjusting the diffusing solutions, scattered crystals of relatively uniform size can be produced in the gel with no banding. It may not be without significance that the above spherulitic structures are best developed in the very sharp and evenly banded jaspers, whereas in those containing scattered martite crystals the banding is much less distinct.

It would appear to be equally improbable that such delicate textures, as shown by these spherulites and micro-shrinkage cracks, could have persisted through any marked degree of metamorphism of the containing banded jaspers, and it would follow that the beds in which they occur have not suffered any appreciable metamorphism since their original consolidation. If this is the case one must assume also that the associated martite, the rhomb structures, and the banding itself were formed during the period of sedimentation and consolidation of the beds and not as a result of later replacement or metamorphism.

Although no true metamorphism has occurred, many of these banded jaspers, as already indicated, show local faulting and folding, in places of an intense nature, but as a rule, even when highly folded, the jasper bands have fractured biscuit-like, and the individual jasper plates have slid along the hematite layers as in the hand specimen shown by Figure 2. In the jasper bands of this and other similar specimens good spherulitic structures were found. Again in the jasper bands of the "puckered" specimen shown in Figure 3, spherulitic structures occur. The latter were presumably formed after the puckering of the soft colloidal sediment, and prior to the complete consolidation of the beds.

Martite (magnetite), when found in sedimentary beds, is usually regarded as a product of metamorphism, but Spiroff (20) has shown that microscopic magnetite crystals associated with magnetite mud can be formed from a mixture of colloidal ferric and ferrous oxides at ordinary temperatures and pressures. However, if special conditions of sedimentation are considered to be necessary for the formation of the martite of the Banded Hematite Jaspers of the Precambrian deposits, there is every reason to believe that special conditions did obtain in Precambrian times.

Quartz Veins and Stringers.—As mentioned previously these banded jaspers contain innumerable veins or stringers of quartz. These are generally more or less perpendicular to the banding, and more often than not they represent infillings along directions of faulting or fracture. They range from quarter to half an inch in width down to microscopic size.

In sections under the microscope they are seen to consist of relatively coarsely bladed quartz generally grown outwards from the cavity wall. In places a little scattered hematite occurs associated with the quartz blades. That these veins represent secondary infillings of quartz along fault fissures or cracks is shown by the fact that one often sees the two parts of a fractured spherulite, one on each side of the quartz-filled cavity, and separated by a distance greater than the diameter of the spherulite.

Similar Structures in other Precambrian Deposits.—As mentioned above martite has long been known in the banded jaspers and iron ores of other areas. Miles (14) has described martite crystals in the jasper bars of Western Australia, and Gruner (7) drew attention to the prevalence of microscopic martite crystals in the iron ores of the Mesabi Range, and remarked on the fact that previous workers had not mentioned martite, although it occurs in great quantity.

The occurrence of micro-spherulitic structures does not appear to have been recorded in these Precambrian jasper bands, although some of the structures described and referred to an organic origin appear to be micro-spherulites. Leith (11) describes "mottled" greenalite granules, i.e. containing minute concretions, which appear to us to be very similar to our spherulites. In describing his Plate XIV he says, "the granule is composed of chert and reddish iron oxide. The chert occurs in small polygonal blocks separated by the oxide. Each of the chert individuals contains in its interior a more or less noticeable nucleus of iron oxide. The matrix is chert. A similar structure has been noted in the iron ores of the Vermillion District and in the Clinton ores. In the latter case the mottled structure is clearly due to the replacement of an organic shell with regular structure." Referring to the granules themselves, and their origin, he says (p. 284): "However the absolute absence of organic structures (aside from the suggestive similarity in shape to granules of known organic origin) must still be kept in mind and the conclusion here given, i.e. an origin in the main from micro-organisms, must be regarded as a tentative one, lacking sufficient basis of direct observation to make it final."

Gruner (8) describes somewhat similar structures in the greenalite granules of the Biwabic formation, and following Leith and others he refers them to a micro-organic origin. Some of these structures as figured (see his Plate 6

opposite page 415) very closely resemble the spherulites described by us. They are described as very uniform in size and about 0.03 to 0.04 mm diameter, which is very close to the dimensions of the spherulites given above.

The minute concretionary bodies described by Wagner (22) in the banded ironstones or "calico rock" of South Africa probably belong to the above types. Of these concretions he says, "The chert itself usually presents a curious spotted or mottled appearance which under high powers of magnification is seen to be due to its being made up of minute dusty oval or rounded bodies separated by thin clear zones. The latter consist of clear colorless quartz and represent the marginal portions of interlocking polygonal grains of that mineral, the interior of which is occupied by the oval bodies already referred to. The dimensions of these vary from .006 to .009 mm along their shorter diameters and from .01 to .02 mm along their greater diameter." The dimensions here given are for the central dusty cores and compare fairly closely with those of the spherulites described in this paper.

There can be little doubt that all the above structures are similar and that they have had a like origin. We have seen no evidence whatever of microorganisms in the Indian banded jaspers, and failing direct evidence to the contrary, we would suggest that all these micro-spherulitic structures have been formed by crystallization from a silica-iron oxide gel or colloid.

Spherulitic structures were described some years ago by one of the writers (19) in sediments of Carboniferous and of Wealden age. They differ from the spherulites described above in many respects, i.e. they are much larger and more perfect, they consist essentially of radiating siderite, and the sediments in which they occur consist of colloidal argillaceous or organic matter. The conclusions then drawn were that these spherulites were formed after sedimentation and prior to the complete consolidation of the beds.

H. C. Jones, in his Memoir on the Iron Ore Deposits of Bihar and Orissa, (10) observed that "nothing has been recorded in the area which suggests that organic agencies had any place in the precipitation or formation of the iron ore." He also noted that "some of the chert bands are full of minute rounded granules," but he did not follow this up any further.

ORIGIN OF THE BANDED HEMATITE JASPER.

Discussions are endless on the special conditions that prevailed at the time of formation of these deposits, conditions not repeated to any noteworthy extent after Precambrian times.

Macgregor (13) has related the occurrences to the Precambrian atmosphere, and has suggested that a relatively high carbon dioxide, and low oxygen content of the atmosphere—due to the absence of plant life as we now know it, and to the fact that up till then no atmospheric carbon had been locked up in the form of organic remains in sediments—would provide optimum conditions for the solution of iron and silica on the exposed land surfaces, and their subsequent deposition.

Gruner (7), to whose work we have previously referred, inquired into the origins of the North American Precambrian deposits in 1922, and concluded that "these sedimentary deposits have been formed first by the weathering of

large areas of greenstone and basalt under warm humid conditions while fresh extrusive rocks and tuffs were being deposited on the land. Vegetation of a low form was abundant and under these conditions silica and iron went into solution and remained so while the organic matter existed." Whether the deposition was in a large inland sea or ocean is a matter of speculation. The suspended matter, he considered, was dropped in deltas, and only the colloids were carried out to the shallow clear water areas. Precipitation of the silica, iron, and part of the organic colloids was caused chiefly by algae and bacteria which used the organic matter for their life processes, and the inorganic silica or iron for the building of their cells or sheaths. Before a freshly precipitated layer of iron-bearing formation could be buried to any depth there was a considerable alteration of the amorphous material. Re-solution and diffusion in one place and re-deposition in another were accompanied by reduction and oxidation of portions of the iron. Most of the organic matter was oxidized to carbon dioxide at this time.

Gruner reports three kinds of granules in the Biwabic formation:

1. Typical oölites
2. Typical greenalite granules
3. Structures which have the size and outlines of greenalite granules "but whose internal structure is different. They appear to be made up of groups or chains of minute concentric rings, which are commonly of chert but may be of a dark graphitic (?) dust or exceedingly minute specks of hematite. Their centers and the matrix in which they are imbedded are practically always of the same material, but different from the rings themselves."

Gruner considered these micro-structures to be algae or bacteria. But the example figured in Gruner's Plate VI A is so similar to the spherulites of our banded jaspers that we feel sure a re-examination of this material (possibly with leaching as before described) would reveal a spherulitic texture. Further, the chance of cutting a slide along a "chain" of granules (whatever they may be) is much less than that of getting the appearance of a chain by a cross section of a layer or sheet of adjoining granules, and we expect that such sheets or layers of spherulites may be found to be fairly common in the Biwabic if they are sought for. Although we do not consider these granules to represent algae or bacteria, nor to be other than inorganic spherulites, this is, of course, no argument against the existence of such organisms, and they may well have played an important part in the formation of these rocks.

If low forms of life of the nature of algae and bacteria existed at the time when the banded hematite jaspers were deposited they would apparently have had very favorable conditions of existence, viz. abundant carbon dioxide, higher temperatures and humidities than prevail today, and presumably few competitors. An abundance of these lowly forms on the exposed land surfaces might have proved very effective in breaking down basic rocks, and carrying away in solution or in colloidal form the iron and the silica. One must not lose sight, however, of the likelihood that iron- and silica-bearing volcanic solutions may have contributed directly to these sediments.

The subsequent deposition of the iron and silica in a more concentrated, but still colloidal form probably followed on the same general lines as for most

sedimentary iron ore deposits, except for the much larger proportion of colloidal silica associated with the iron. Partial oxidation of the iron (and possibly associated organic matter) would lead to reduced solubility of the iron and its precipitation as a mixed colloid, from which hematite, magnetite, and siderite would derive. It is assumed that this colloidal precipitate would carry down and occlude any small crystals of carbonate or magnetite already formed and held in suspension during sedimentation.

The lenticular or regular banding could have been caused by local, or general, variations in the proportion of iron oxide to silica in the colloidal sediment. The silica bands are scarcely ever free from iron oxide particles, whereas the iron oxide bands are generally almost pure, such silica as they contain being commonly secondary. This might imply conditions of deposition with a continuous supply of iron oxide and an intermittent supply of silica. Such conditions could have been provided by an organic source for the iron, with intermittent irruptions of siliceous solutions from volcanic sources.

On the other hand there may have been, as suggested by Moore and Maynard, intermittent supplies of mixed material, with more rapid settlement of the iron than the siliceous colloids, and this seems to us the most probable cause of the alternation, though Wagner (*22*) considers that a possible explanation is "suggested by certain of Liesegang's experiments on rhythmic precipitation."

But whatever the initial cause of the banding, the local puckering and crumpling of these rocks were undoubtedly brought about while the material was still in a soft or plastic state, and could have been caused by local movements of the sedimentary floor, possibly associated with compaction of the lower layers, or perhaps vulcanicity. It is also possible that changes in the thixotropy of colloidal layers or lenticles of differing consistency and density may have given rise to slip movements followed by puckering. The tangled "knot" of the iron oxide layer shown in Figure 3 was obviously caused by drag movements.

We have made it clear that we share the general opinion that these deposits have features that are unique, but Bruce (*2*) on the contrary states that "the conception that rocks of Precambrian age have characteristics entirely different from those of later ages has, little by little, been shown to be untrue." In effect, he agrees that if all the iron formations of the Precambrian had been formed in the same way, the prodigious quantities of iron would seem to justify the conclusion that they are the results of unique conditions. But, says Bruce, "it becomes increasingly evident that formations even of somewhat similar appearance differ in the details of their composition, and have evidently formed under different conditions. It is not necessary, therefore, to assume widespread operation of a single type of process. Moreover the Precambrian Iron Formations, restricting the term to those rocks that contain no clastic material, are so similar in many other respects to sediments of later epochs that it seems impossible that the processes under which they were formed were unique and occurred only in Precambrian times. It is more likely that accumulation and precipitation took place under some specially favourable combination of circumstances that occurs seldom, but that is not restricted to any age."

So far as we are aware—with a fairly wide acquaintance with these rocks in India, Brazil, South and West Africa, and the Lake Superior region—they do not differ much in "the details of their composition." Such differences as do occur are mainly those that would be produced by different agencies acting upon almost identical original material. The banded rock in India seems to be little altered from its original condition, save that the magnetite is almost completely changed to martite, which again is a common feature of the banded jaspers of other areas. In Brazil, the itabirites have been somewhat metamorphosed, and the silica is recrystallized. The hematite is often specular and the silica is finely saccharoidal, but the composition is the same as in the Indian material. In Mauretania the iron oxide also is recrystallized. Where granites or other igneous intrusions occur it is to be expected that iron silicates will form, possibly with additional ingredients derived from the granites. Thus, at Gorumahisani iron mine, in the former state of Mayurbhanj, India, we get banded grünerite-hematite rocks; also more extensively in the banded iron ores of Bastar State, to the southwest of Singhbhum.

In South Africa we have seen "Calico rock" that might have come from Noamundi mine in Singhbhum, and the jaspillites of the Marquette and Vermillion areas, in hand specimens, are very closely similar to the Indian banded jaspers. Though there are differences between the Vermillion jaspillites and those of the Mesabi and Biwabic ranges these differences are not such as to suggest an important difference in origin. The banded jaspers of Labrador, of West Africa, and South Australia also closely resemble the Indian rocks.

Tanton (21), in a presidential address to the Royal Society of Canada, states that the iron range rocks "are not of surficial or sedimentary origin. They meet the host rocks in which they occur as irruptive bodies or primary replacement deposits." This general conclusion is based largely on the evidence provided by the Steep Rock Lake deposits, in which, according to H. M. Roberts and M. W. Bartley (18), "the characteristic banded iron formation is lacking," and also on structures in certain globule-bearing quartz porphyries. So far as our deposits are concerned there is no justification for the use of the term "host rock." The banded jaspers and their derived slump ores lie conformably on a bedded rock that was originally considered by Jones (10) to be a shale, but which we showed was a tuff, commonly silicified in a patchy manner. They are overlain conformably by phyllites, or unconformably by a conglomerate.

The Indian banded rocks appear to have been less altered from their original condition than those in many of the other areas. The beds have been folded to a moderate degree, but although the pressures have been sufficient in some places to cause intimate fracturing of the banded hematite jaspers they have not been so great as to recrystallize either the silica or the iron oxide, and thus the microscopic textures that we have described are still preserved, even in the fractured rocks. These spherulitic structures and shrinkage cracks point definitely to the colloidal sedimentation of these deposits. They are absent in the Brazilian and Mauretanian deposits, and also in some of the Australian samples we have collected. They would, of course, be destroyed by recrystallization.

When we consider the workable iron ore bodies it is possible that there are differences in origin. The Indian ore bodies, we consider, have been formed from the banded hematite jaspers by the action of meteoric waters. Elsewhere possibly hydrothermal agencies may have removed the silica bands and enriched the iron ore bodies. But we are not concerned with these secondary changes, and the manner of formation of the large workable ore bodies from the banded rocks is outside the scope of this paper.

We wish to express our thanks to Dr. H. Crookshank, who sent us samples of the Bailadila banded ores from Bastar State for examination; to Dr. W. D. West and Mr. W. H. Johnson, for microphotographs of some of our slides, and to Professor C. E. Marshall for kindly making some particularly thin slides of the banded hematite jaspers for us.

SURREY, ENGLAND,
Dec. 13, 1951.

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DIFFERENTIAL THERMAL CURVES OF SELECTED LIGNITES.[1]

W. J. SMOTHERS AND YAO CHIANG.

ABSTRACT.

The objectives of this study were: (1) To determine whether the use of the differential thermal method could increase the knowledge of the reactions which take place when lignites are heated under controlled conditions; (2) to study the relationship of heating curves of related materials to those of lignite; and (3) to correlate the X-ray patterns of lignites with the differential thermal curves of lignites and similar materials.

The differential thermal method is limited to the identification of the reactions on heating as being either endothermic or exothermic, and supplementary work sometimes is necessary to identify products of these reactions. The principle of differential thermal analysis is the measurement of the difference in temperature between that of a reacting sample and that of an inert material as they both are heated. A plot of differential thermal temperature *vs.* sample temperature illustrates reactions involving the exchange of heat.

EQUIPMENT.

THE sample holder was a stainless steel block as shown by Berkelhamer.[2] Chromel-alumel thermocouples, 22-gauge, were connected to a Leeds and Northrup X–Y recorder. Variable amplification of the differential temperature was accomplished by use of a DC amplifier. A Hevi-Duty wire-wound furnace for heating the sample block was controlled by a motor-driven voltage controller ("Variac").

DESCRIPTION OF SAMPLES.

Samples of Arkansas lignite were collected at various locations by University of Arkansas personnel and stored in brown-colored bottles away from light for approximately 3 years. Before analyses were begun a fresh control sample, collected at one of the same locations, was obtained from the Geology Division of the Arkansas Resources and Development Commission. Most of the North Dakota samples were supplied by the U. S. Bureau of Mines laboratory at Grand Forks, North Dakota. (The Velva lignite came from the Truax-Traer Coal Company at Minot; the Fort Harrison sample was furnished by the War Department.)

A comparison of the proximate analyses and heating values of the Arkansas lignites obtained by the University of Arkansas with those obtained by the

[1] The authors wish to express their appreciation to those who submitted samples for this investigation. The assistance and suggestions of the staff of the Chemistry and Geology departments at the University of Arkansas are gratefully acknowledged. Presented before the Society of Economic Geologists, Detroit, November 8–10, 1951.

[2] Berkelhamer, Louis H., Differential thermal analysis: U. S. Bur. Mines Tech. Paper 664, pp. 38–55, 1945.

TABLE I

COMPARISON OF PROXIMATE ANALYSES AND HEATING VALUES OF ARKANSAS LIGNITES OBTAINED BY UNIVERSITY OF ARKANSAS AND U. S. BUREAU OF MINES

ARKANSAS LIGNITE SAMPLE	PROXIMATE ANALYSES						HEATING VALUES (BTU/lb.) *Air-Dried Basis*
	Air Dried				Moisture, Ash Free		
	Moisture	VM	Fixed C	Ash	VM	Fixed C	
USBM-46084	10.9	42.6	30.4	16.1	58.4	41.6	9170
UA-A	7.5	45.1	27.9	19.5	61.8	38.2	9805
USBM-46086	13.3	43.6	28.9	14.2	60.2	39.8	9390
UA-C	7.3	44.6	27.1	21.0	62.2	37.8	9836
USBM-46087	11.4	33.2	22.4	33.0	59.7	40.3	6620
UA-D	6.9	35.3	22.3	35.5	61.3	38.7	6588
USBM-46107	11.3	43.2	29.6	15.9	59.2	40.8	9270
UA-E_1	6.9	45.5	28.7	18.9	61.3	38.7	6619
USBM-46108	15.3	41.8	33.5	9.4	55.5	44.5	9380
UA-E_2	11.0	42.0	33.5	11.5	54.2	45.8	10020
USBM-46109	13.7	47.5	30.7	8.1	60.7	39.3	10250
UA-E_3	10.3	45.9	34.0	9.8	57.4	42.6	11320
USBM-46110	13.5	43.8	31.2	11.5	58.4	41.6	9680
UA-F	10.2	39.2	30.9	19.7	55.9	44.1	9557
USBM-46088	9.8	41.0	32.8	16.4	55.5	44.5	9240
UA-G	9.2	37.0	31.2	22.6	54.3	45.7	9248
UA-G (Fresh) . . .	12.3	39.1	29.5	19.1	57.0	43.0	-----
USBM-46089	9.1	44.5	34.6	11.8	56.2	43.8	10140
UA-H	7.0	42.3	38.3	12.4	52.5	47.5	10392
USBM-46096	4.0	15.0	9.2	71.8	62.0	38.0	-----
UA-I_1	4.1	10.9	8.5	76.5	56.4	43.6	-----
USBM-46097	8.1	17.2	15.1	59.6	53.3	46.7	3570
UA-I_2	4.6	12.2	12.3	70.9	50.0	50.0	2260

U. S. Bureau of Mines [3] is presented in Table I. The locations from which samples were collected are described in detail in the U. S. Bureau of Mines publication.

EXPERIMENTAL PROCEDURE.

The lignites were ground to pass a 100-mesh screen and then diluted with minus 100-mesh calcined alumina (A-1 calcined alumina was obtained from Aluminum Ore Company, East St. Louis, Illinois) so that the exothermic reactions would not exceed a temperature of 1000° C, the upper limit of

[3] Selvig, W. A., Ode, W. H., Parks, B. C., and O'Donnell, H. J., American lignites: U. S. Bur. Mines Bull. 482, pp. 63, 1950.

measurement with the available equipment. In most samples the lignite concentration was 25 percent but some analyses were made with samples of 15 percent concentration. The lignite-alumina mixture was packed in the sample hole and calcined alumina was packed in the hole for the inert material. The

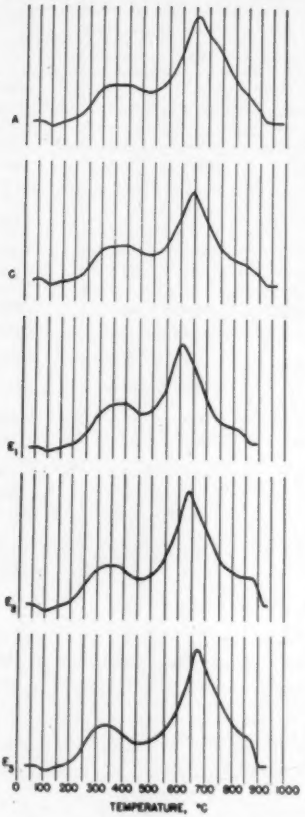

FIG. 1. Differential thermal curves of 15 percent Arkansas lignites heated in air.

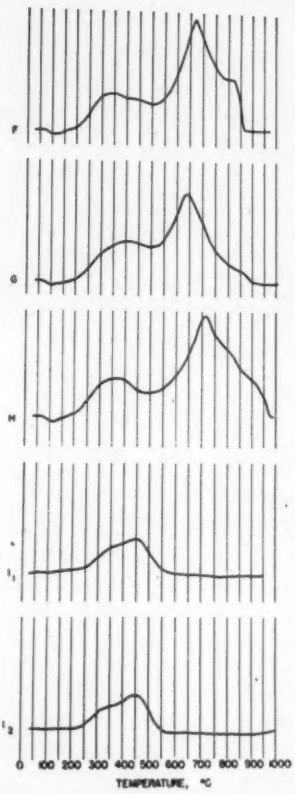

FIG. 2. Differential thermal curves of 15 percent Arkansas lignites heated in air.

block was then heated at the rate of 12° C per minute. There was no cover on the sample holder; therefore, upon heating the sample oxidized in an atmosphere of air. In some cases nitrogen was introduced into the furnace to retard the oxidation.

ARKANSAS LIGNITE CURVES.

Differential thermal curves of Arkansas lignites (15 percent concentration) heated in air are similar (Figs. 1 and 2), the greatest difference being in samples I_1 and I_2 which were collected in Dallas County, Arkansas. These two lignites have the lowest heating values of this group (Table I). When the concentration of lignite was increased to 50 percent, sample I_1 produced a curve with a proportionate increase in height of the exothermic peak and a slight expansion in the horizontal direction. There was no resolution of the exothermic peak to produce curves similar to others in the group.

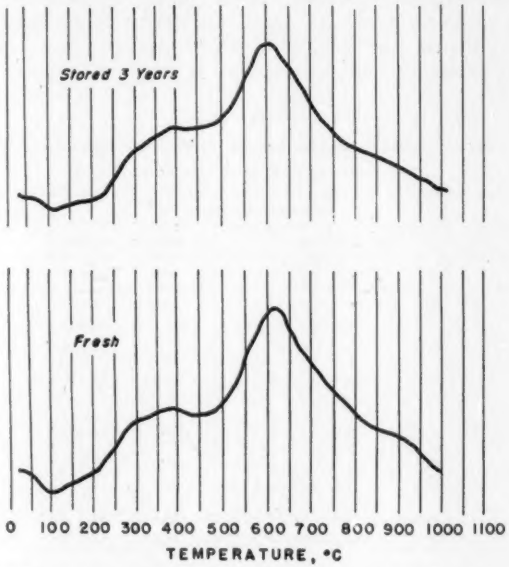

FIG. 3. Differential thermal curves of 25 percent stored and fresh lignite G.

The curve for lignite F (collected at Old Big House Mine near Chidester, Arkansas) was interesting because an exothermic peak was indicated at 820° C (Fig. 2). This peak may be present, to a lesser degree, in some of the other curves.

The majority of these curves are similar somewhat to those shown by Grim and Rowland [4] for heating diluted vitrain and clarain in air. Their low temperature exothermic reaction between 300–400° C corresponds to the lignite peak at the same temperature range. The more intense exothermic peak at 500–550° C corresponds to the more intense lignite peak, usually between 550–700° C. The lignite curve shows an additional exothermic peak, as in F, which occurs at 820–860° C.

[4] Grim, R. E., and Rowland, R. A., Differential thermal analysis of clays and shales, a control and prospecting method: Am. Ceram Soc. Jour., vol. 27, pp. 65–76, 1944.

EFFECT OF STORING.

A fresh lignite sample (G) was obtained from the Garner Mine near Chidester, Arkansas, to determine whether storing for a number of years greatly affected the differential thermal curve on heating in air (Fig. 3). The comparison of proximate analyses of the stored and fresh samples is shown in Table I. No great difference between the two curves was observed.

NORTH DAKOTA LIGNITE CURVES.

The proximate analyses and heating values of North Dakota lignite samples are shown in Table II. Data supplied by the Grand Forks laboratory are compared to that obtained by the Pittsburgh laboratory on samples from from the same locations, as described in the lignite report.[3]

TABLE 2

COMPARISON OF PROXIMATE ANALYSES AND HEATING VALUES OF NORTH DAKOTA LIGNITES OBTAINED BY U. S. BUREAU OF MINES

North Dakota Lignite Sample*	Proximate Analyses					Heating Values (BTU/lb.) Moisture-Free Basis
	Moisture Free			Moisture, Ash Free		
	VM	Fixed C	Ash	VM	Fixed C	
USBM (P) - 45800	43.2	47.5	9.3	47.7	52.3	10920
ND-Velva	43.7	48.3	8.0	47.5	52.5	-----
USBM (P)- 45809	41.3	49.1	9.6	45.6	54.4	12430
ND-Baukol-Noonan	41.8	46.9	11.3	47.1	52.9	11000
ND-Dickinson	43.8	44.0	12.2	49.9	50.1	10600
USBM (P) - 45825	40.2	47.5	12.3	45.8	54.2	10790
ND-Kincaid	39.2	47.9	12.9	45.0	55.0	10570
USBM (P) - 45548	41.4	49.0	9.6	45.9	54.1	11050
ND-Beulah	39.3	41.5	19.2	48.6	51.4	9810

* USBM (P)= Analysis made by U.S. Bureau of Mines laboratory at Pittsburgh, Pennsylvania.
ND prefix= Analysis made by U. S. Bureau of Mines laboratory at Grand Forks, North Dakota.

Differential thermal curves of 25 percent concentration of North Dakota lignites (Fig. 4) show a difference in the first exothermic peak when compared with Arkansas lignite curves. A shift of the first exothermic peak to a higher temperature is shown on the curve for Beulah lignite. A step-wise first peak is obtained in curves of Kincaid and Baukol-Noonan lignites.

OTHER LIGNITE CURVES.

A sample of Miocene lignite from the Queen Charlotte area, British Columbia, was obtained from W. L. Whitehead. This sample and other carbonaceous materials were investigated, using vacuum differential thermal

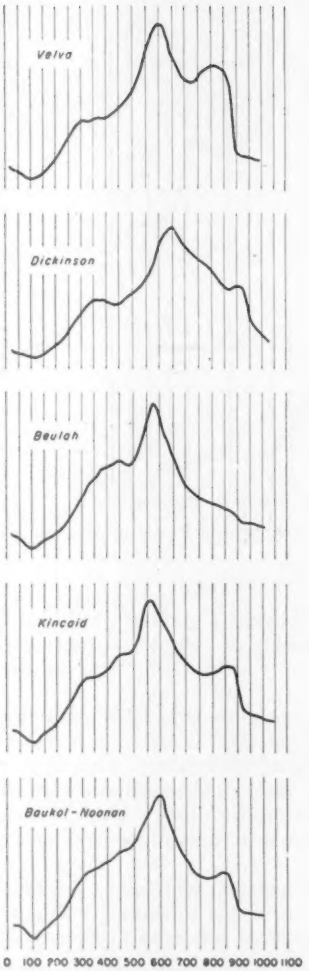

FIG. 4. Differential thermal curves of 25 percent North Dakota lignites heated in air.

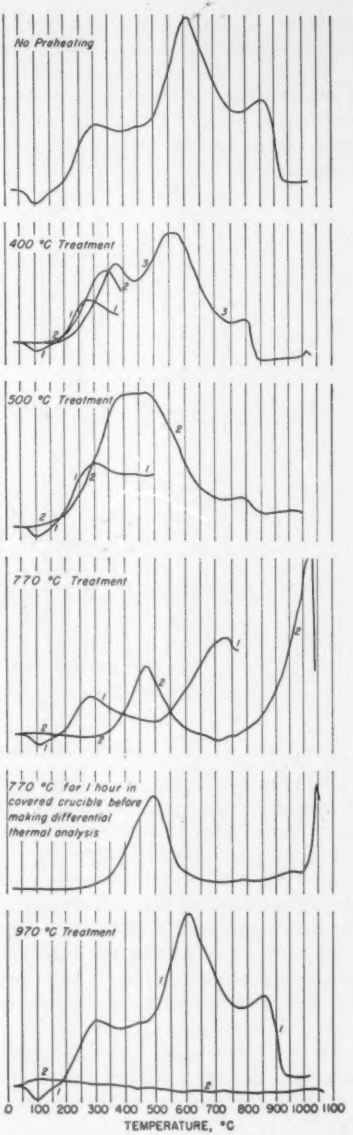
No Preheating
400 °C Treatment
500 °C Treatment
770 °C Treatment
770 °C for 1 hour in covered crucible before making differential thermal analysis
970 °C Treatment
0 100 200 300 400 500 600 700 800 900 1000 1100
TEMPERATURE, °C

FIG. 5. Effect of preheating 25 percent lignite F samples in air.

analysis.[5] A similarity of the lignite vacuum thermogram to that of lignin and the apparent presence of cellulose is shown by their data.

Curves of the War Department lignite from Fort Lincoln at Bismarck, North Dakota, and the Queen Charlotte lignite (Fig. 6) show similar first exothermic peaks. These first peaks differ in appearance from those of the other North Dakota and Arkansas lignites which were studied in this investigation.

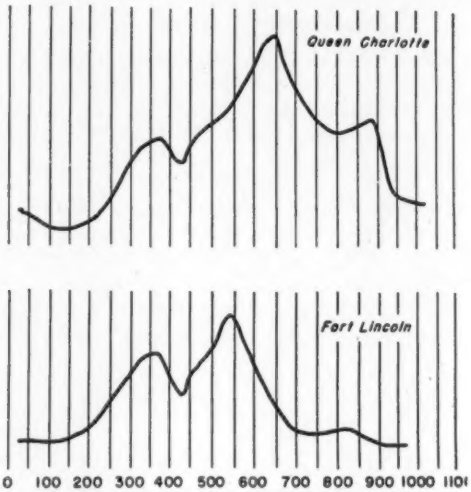

FIG. 6. Curves for 25 percent Queen Charlotte and Fort Lincoln lignites.

EFFECT OF HEAT TREATMENT.

Samples of 25 percent concentration of lignite F mixtures were heated in air to various temperatures and cooled quickly to room temperature with an electric fan. This procedure was repeated in some cases. Curves showing these results are given in Figure 5.

400° C—Successive heatings to this temperature with intermediate cooling show elimination of the endothermic peak at 100° C after the first heating. The first exothermic peak is shifted to higher temperatures with an increase in intensity. Completing the run for the third heating shows a shift of the second exothermic peak to a lower temperature with little change in intensity. The third exothermic peak shows a reduction in intensity as well as a shift to lower temperature.

500° C—Successive heatings show an apparent merging of the first and second exothermic peaks of the original curve due to shifting and intensity changes. The third exothermic peak is reduced still more in intensity.

[5] Breger, Irving A., and Whitehead, Walter L., A thermographic study of the role of lignin in coal genesis: Conference on the Origin and Constitution of Coal, Sponsored by Nova Scotia Department of Mines and Nova Scotia Research Foundation, pp. 120–40, 1950.

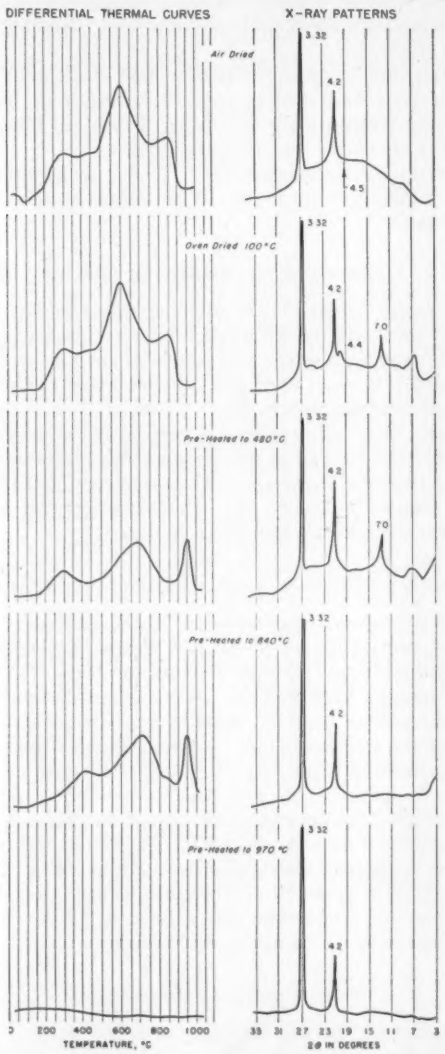

FIG. 7. Differential thermal curves and X-ray patterns of preheated lignite F.

770° C.—The merged first and second exothermic peaks of curve 2 are reduced in intensity with the appearance of a very sharp high intensity exothermic peak at 1035° C.

770° C—Preheated sample—Preheating undiluted lignite F to this temperature for one hour in a covered crucible furnished the material for preparing a 25 percent concentration sample for the differential thermal heating. This curve is very similar to the preceding curve.

970° C—Heating of the diluted lignite to this temperature in an atmosphere of air is sufficient to form ash. The second heating shows the inert character of the ash.

X-RAY STUDY OF PREHEATED LIGNITE.

A Norelco, copper target, X-ray machine was used to obtain the spectrometer traces shown with the differential thermal curves of preheated lignite F (Fig. 7). The undiluted lignite was heated in an open crucible to the temperatures indicated. Samples of 25 percent concentration were then prepared for differential thermal analysis in air.

The two quartz lines on the X-ray pattern, 3.32 and 4.2 Å, are superimposed on the broad 4.5 Å peak of the carbonaceous material. In some cases the 7.0 Å line of kaolinite is present. The symmetry of the 4.5 Å peak and its intensity is reduced by oven drying. Further preheating reduces the peak intensity until it is eliminated when ash is produced.

INTERPRETATION OF X-RAY PATTERNS OF LIGNITES.

Identification of carbonaceous materials in the lignites is complicated by the similarity in X-ray patterns of lignin (Meade Corporation, Chillicothe, Ohio), dehydrated cellulose (method of Cross and Bevan [6]), and alpha cellulose (Forest Products Laboratory). All of these substances have their maximum peak at 4.3–4.4 Å. One or more additional low intensity peaks is present for lignin and alpha cellulose. Cotton celluloses from the Institute of Paper Chemistry and the University of Arkansas show the X-ray pattern of native cellulose with its main peak at 3.9 Å.

All of the Arkansas lignites examined, except the high ash samples I_1 and I_2, showed a broad low intensity peak at 4.2–4.5 Å. In five of these samples an additional lower intensity peak was present at 2.3–2.5 Å.

The higher intensity peak for four North Dakota samples was 3.8 Å. Two other samples from this state had a peak at 4.2 Å. Lower intensity peaks were present on all six samples at 2.3–2.6 Å.

INTRODUCTION OF NITROGEN.

Nitrogen was forced into the heating zone of the furnace through a hole which had been drilled in the back of the furnace. This nitrogen reduced the amount of oxidation of the lignite. The rate of nitrogen flow was found to affect the shape of the differential thermal curve (Fig. 8). The first exo-

[6] Cross and Bevan, Phil. Mag., vol. 13, pp. 327, 1882.

thermic peak is much more difficult to suppress than the higher intensity second exothermic peak. An endothermic peak at approximately 890° C becomes more evident as the rate of nitrogen is increased. This raises the possibility that the endothermic peak may be present, even in air heatings,

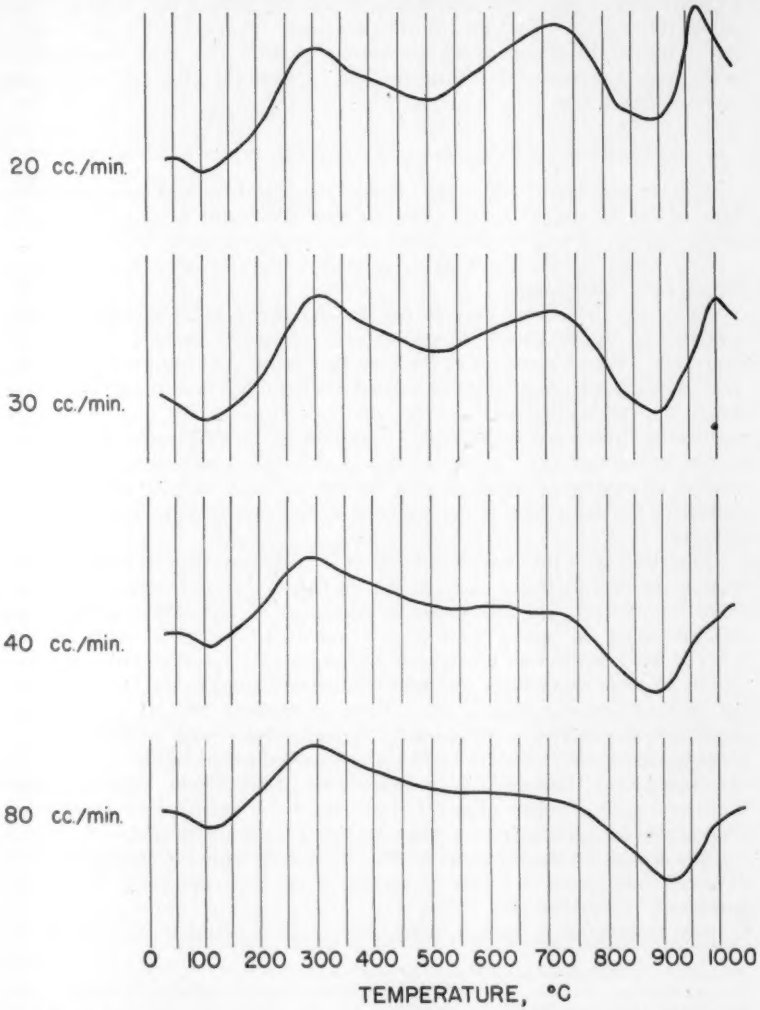

FIG. 8. Effect of nitrogen flow rate on the differential thermal curve of 25 percent lignite F.

superimposed on the exothermic reactions taking place. The third exothermic peak is apparently eliminated. Subsequent heatings were made with a minimum nitrogen flow rate of 40 cc per minute.

Other tests were made in which the metal sample holder was placed inside a quartz tube. This tube was placed inside the furnace and nitrogen was passed through the quartz tube at different rates. A rate of 20 cc per minute was sufficient to eliminate all exothermic peaks. The main endothermic peaks were apparent at 100° and 940° C. Practically all of the curve was below the base line.

EXPLANATION OF DIFFERENTIAL THERMAL PEAKS OF LIGNITES.

Oxygen was passed (20 cc per minute) through the quartz tube containing lignite F in the sample block. The differential thermal curve obtained and partial analysis of evolved gases aided in explaining reactions taking place.

The initial endothermic peak at approximately 110° C is due mainly to driving off sorbed water.

The first exothermic peak is due to decomposition of the lignite with evolution of approximately equal volumes of carbon dioxide and carbon monoxide. Water given off at the first exothermic peak was not measured. This peak was reproducible when heating in air and when nitrogen was introduced into the heating zone. This same type reaction was observed under vacuum by Breger and Whitehead.[6] Heatings in the quartz tube with a flow of nitrogen across the sample eliminated this first exothermic peak. The amount of oxygen required for this reaction is much smaller than that required for the other exothermic reactions when heating under oxidizing conditions.

The shifting of the first exothermic peak to higher temperatures by preheating the lignite (Fig. 5) may be due to partial decomposition with subsequent polymerization. This is not a simple, rapid reversible-type reaction, because cooling the lignite in the furnace just after passing this peak, showed a fairly rapid decrease in intensity of the exothermic reaction with a further cooling to room temperature and no endothermic change in the sample. It is not believed that this peak is due entirely to breaking off OH groups from cellulose-type material as proposed by the early differential thermal work of Hollings and Cobb.[7] Curves of 25 percent concentration lignite F and those of polyethylene (through Visking Corporation, Little Rock, Arkansas) both in air and with nitrogen (Fig. 9) show that a low temperature exothermic peak occurs for polyethylene in which no OH groups are present.

The second exothermic peak is due to burning with evolution of carbon dioxide. Nitrogen atmosphere or vacuum [5] eliminates this peak. The temperature at which this peak occurs shifts within limits of approximately 150° C when an attempt is made to reproduce curves obtained by heating lignite in air.

[7] (a) Hollings, Harold, and Cobb, John William, Thermal phenomenon in carbonization: Gas Lighting Jour., vol. 126, pp. 917–24, 1914.

(b) Hollings, Harold, and Cobb, John William, A thermal study of the carbonization process: Chem. Soc. Jour., vol. 107, pp. 1106–15, 1915.

A high temperature endothermic peak is evident under nitrogen atmosphere and may be present when heating in air. This is accompanied by a marked gas evolution.

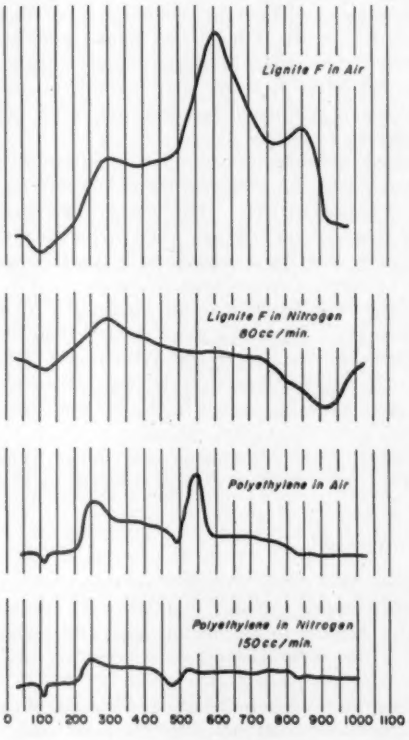
Lignite F in Air
Lignite F in Nitrogen
80cc/min.
Polyethylene in Air
Polyethylene in Nitrogen
150cc/min.
0 100 200 300 400 500 600 700 800 900 1000 1100

FIG. 9. 25 percent lignite F and 25 percent polyethylene when heated in air and in nitrogen.

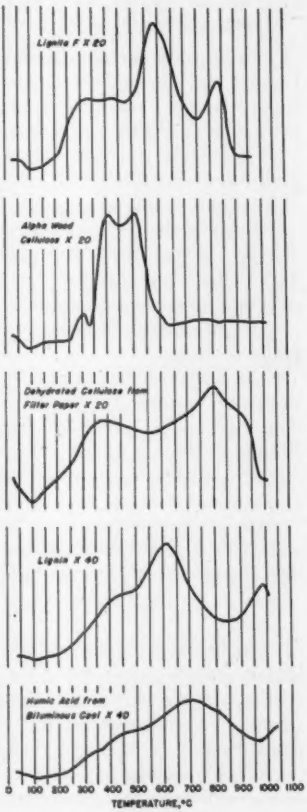
Lignite F X 20
Alpha Wood Cellulose X 20
Dehydrated Cellulose from Filter Paper X 20
Lignin X 40
Humic Acid from Bituminous Coal X 40
0 100 200 300 400 500 600 700 800 900 1000 1100
TEMPERATURE, °C

FIG 10. Comparison of 25 percent lignite F with like concentration of other materials when heated in air.

The final exothermic peak at approximately 800–900° C varies in relative intensity with the various lignites but does not have a temperature shift of more than 50° C on duplicating results with any one sample. Introduction of oxygen into the quartz tube arrangement shifted this third peak to coincide almost with the second exothermic peak. Lower temperature decomposition, around the first exothermic peak, may produce at least two different types of

products which may oxidize at different temperatures to produce the second and third exothermic peaks. The oxidation temperature also depends on the availability of oxygen during the heating.

CORRELATION OF LIGNITE CURVES WITH THOSE FOR OTHER MATERIALS.

Twenty-five percent concentration curves of alpha cellulose from delignified Douglas fir (Forest Products Laboratory), dehydrated cellulose from filter paper,[6] lignin (Meade Corporation, Chillicothe, Ohio), and humic acid extracted from a Pittsburgh seam coal (from H. C. Howard) were compared with the curve for lignite F when heated in air (Fig. 10). Different amplifications of the differential temperature are noted but were necessary because slightly different sample holders were used.

Breger and Whitehead mentioned difficulty in reproducing differential thermal curves with conventional equipment but indicated that some interesting results were obtained (private communication). This led to their constructing a vacuum system to study reactions on heating. The major portion of any one of their lignite thermograms shows a resemblance to the thermogram for lignin.

The lignin curve (Fig. 10) is very similar to that for lignite F. This similarity to most of the other lignite curves is perhaps more marked than the thermograms of lignite and lignin obtained by Breger and Whitehead.[5] No definite indication of the presence of a cellulose-type material was shown for the air heatings in contrast to its presence being shown in the vacuum work of the above authors.

The curve for humic acid extracted from bituminous coal shows some similarity to the lignite curves. The step-wise first exothermic peak is like that of some North Dakota lignites.

SUMMARY.

The conditions under which lignites and other carbonaceous materials are heated greatly affect the differential thermal curves. Similarity of certain portions of the curves are shown for heating in air, in nitrogen, and under vacuum. Differences in the curves for these various conditions are also pointed out.

X-ray investigation of the lignites does not permit clear-cut identification of the carbonaceous ingredients. The X-ray patterns, although quite similar to those of lignin, do not rule out the possibility that cellulose is present in some stage of decomposition.

The differential thermal curve of lignite cannot be correlated with the X-ray pattern to the extent that differences in the heating curve can be anticipated by the diffraction pattern. This is illustrated by the differences in the thermal curves and X-ray patterns of the Arkansas and North Dakota samples.

When lignites are heated in air, the resulting curves, in most instances, are strikingly similar to those obtained from lignin.

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INSTITUTE OF SCIENCE AND TECHNOLOGY,
FAYETTEVILLE, ARK.,
Dec. 1, 1951.

ANTIMONY DEPOSITS OF TUSCANY.[1]

G. DESSAU.

ABSTRACT.

For at least 150 years, Italy has been a small producer of antimony, with an output, during the present century, of a few hundred tons annually. Mining is now concentrated in Sardinia and Tuscany; yield of metal during 1950: Tuscany 424 metric tons, Sardinia 140.

Ore deposits of southwestern Tuscany are genetically related to magmatic activity which began in the Miocene, when the upheaval of the Apennines was already well under way and produced fairly near-surface granitic intrusions, and also effusions of trachyte (mainly Quaternary) (Monte Amiata). Post-volcanic manifestations such as steam jets (*soffioni*) and thermal springs are still active. Genetically allied with the trachyte of Monte Amiata are the mercury and antimony deposits.

A partial stratigraphic column is:

Tertiary: Macigno. Sandstones and clays
Triassic: Calcare cavernoso. Dolomitic limestone
Permo-Carboniferous: Verrucano. Slates

The antimony mineralization consists of quartz bodies with stibnite. The orebodies are localized at the contact (stratigraphic or tectonic) between limestone and the overlying impermeable Tertiary sandstones. In about half of the dozen known occurrences the limesone is the Triassic Calcare cavernoso. In the others the limestones are of diverse ages but play a similar role.

Structurally the ore is localized by faults of two sets, north-south and northwest, both developed after the Apennine folding and active until Quaternary times.

Three deposits, Poggio Fuoco, Tafone, and Montaùto are described in detail; others are covered more briefly.

INTRODUCTION.

STUDENTS of mineral deposits will have noticed references to the ore deposits of Italy and to the two main metallogenetic provinces, Sardinia and Tuscany, but the references are vague, up-to-date information is scarce, and recent papers are lacking.

Numerous papers on the general geology and ore deposits of Tuscany appeared during the past century and the first decade of the present one. To this period belongs, for instance, De Launay's "Metallogenie de L'Italie" (3).[2] These investigations culminated in the lifetime's work of Bernardino Lotti who, during his sixty years of service with the Italian Geological Survey, made the geological maps on a scale of 1:100,000 of the whole area, which he described also in several volumes of Memoirs (4) and in a host of shorter

[1] The original manuscript of this paper has been edited and somewhat abridged by H. E. McKinstry.

[2] Numbers in parentheses refer to Bibliography at end of paper.

publications. A mining engineer, he was also keenly interested in economic geology, and especially in ore deposits. His views made partly available to the non-Italian public through a few papers in the "Zeitschrift für praktische Geologie" (2), and collected by him during his late years in a juicy little book on Mineral Deposits (5), were largely in advance of the times and are successfully standing the test of later investigations.

Later, and until very recent years, study of the mineral deposits of Tuscany and especially of the geology of its western or Tyrrhenian strip have been neglected. In fact there was a conspicuous lack of scientific interest in Italian mineral deposits in general during the twenties and thirties. More recent years have seen a renewal of interest in Tuscany, including its *Catena Metallifera* (as the older geologists called its southwestern mineral-bearing strip) mainly through the work of R. Signorini, C. I. Migliorini, and of the geological departments of the universities of Florence and Pisa, directed respectively by G. Merla and L. Trevisan.

In the case of the mineral deposits, very little has been done, with the exception of the valuable data collected (even if not yet fully worked out), as a result of extensive mining, hundreds of deep borings, geophysical surveys, and the geological work of L. Ogniben and others, by the largest mining company in Italy which earns large profits from its great pyrite mines in the area. But unfortunately a screen of secrecy has been clamped on all this information, thereby retarding the progress of knowledge about an area that excels both in scientific interest and practical importance.

GEOLOGICAL FEATURES OF WESTERN TUSCANY.

As recent geological studies in Tuscany have occasioned fresh controversy, the reader of the following condensed geological introduction should bear in mind the fact that views regarding the geologic history are in a somewhat fluid state.

Leaving out of consideration the island of Elba, the oldest formation of southwest Tuscany is the Verrucano, a complex whose thickness is unknown but must be at least several hundred meters. It consists of schistose sandstones with subordinate slates, and hard cemented coarse conglomerates;[3] this complex is the result of a very mild, upper-epizone metamorphism of a molasse-formation which was deposited in the foreland of a Hercynian mountain chain, which presumably extended farther to the west, where the depths of the Tyrrhenian Sea now exist. The age of the Verrucano is Permo-Carboniferous, and of its metamorphism, Alpine.

The Verrucano is overlain by the Calcare cavernoso (cavernous limestone) with a contact which is variously interpreted as transgressive or tectonic. The Calcare cavernoso, as seen on or near the surface, is a very hard brecciated dolomitic limestone, conspicuous in the landscape on account of its rugged topography and its sparse and stunted trees; one of the causes of its barrenness

[3] In international usage, the term "Verrucano" is generally applied only to this type of cemented conglomerates, which however are only a very minor constituent of the whole formation.

is its subterranean hydrology; all the surface waters quickly disappear in crevices and sink-holes. It has been convincingly proved that the Calcare cavernoso is, like the Alpine Rauhwacken, a product of the transformation, within the realm of deeper vadose water circulation, of a lagoonal deposit of alternating layers of anhydrite and dolomite. Its age is Upper Triassic, its variable thickness attains well over one hundred meters.

In many localities there follows conformably, above the Calcare cavernoso, a thick and little disturbed series of mainly calcareous deep-water sediments, representing the whole of the Jurassic and Cretaceous periods. In other places, however, often only a few kilometers away from where the complete series can be observed, there is a remarkable gap and the Tertiary sediments rest directly on the Calcare cavernoso. Various theories have been formulated to explain this gap, but none of them, in the author's opinion, seems entirely satisfactory.

These Tertiary sediments, which thus lie either on top of the Cretaceous or directly on the Calcare cavernoso, begin with the soft, micaceous Macigno—sandstones and mudstones—which can be dated as Oligocene by beds of nummulitic limestone interlayered with their basal strata.

Shortly before the deposition of these nummulitic limestones and of the Macigno, the upheaval of the Apennines began. According to the modern Tuscan geological schools, this orogenesis can be visualized in the following way: a first "wrinkle," stretching in northwest-southeasterly direction, began to bulge up in the west, presumably not far from what is today the Tyrrhenian coast; it began to shift slowly towards the east, with only the deformation advancing, like a rolling sea-wave, where the wave-form advances but not the water. When the first "wrinkle" had travelled far enough, another, and still others, rose and followed the same northeastward migration.

At some distance from these mountain "wrinkles," both in front and in back of them, sandy material resulting from their denudation deposited, and often was mobilized again through submarine slumping; travelling further in muddy streams, it was finally deposited, forming the Macigno, with its characteristic graded bedding. When the "wrinkles" came still nearer, avalanches of chaotic material, a clayey dough carrying fragments of every possible size, from a mountain downwards, of all sorts of rocks of earlier sedimentation, but mainly of limestones and sandstones, covered all the exposed older rocks as a widespread blanket. This chaotic clayey formation is the Argille scagliose of the Italian authors.

Shortly afterwards a fault-tectonics was superimposed on the "wrinkle"-tectonics. It followed the same main directions and was broadly due to the same deep-seated phenomena; it may represent a "distension"-period after the compression and folding. A system of northwest-southeast striking faults divided western Tuscany into rows of blocks, which were displaced hundreds of meters vertically and tilted, so as to create two sets of inclined steps, which dip away from one central axis. The resulting great differences in height were partially subdued by erosion. A second system of faults, striking north-south, was initiated more or less at the same time as the first system. Movement along these two fault-systems continued until Quaternary times.

In the elongated bays between the various "wrinkles" and faulted blocks are the clastic sediments which were variously deposited in marine brackish and fresh-water environments. They range from conglomerates to clays, in a whole cycle of shallow marine ingression and regression. The age of these sediments is Mio-Pliocene, and their middle part broadly corresponds to the economically important "gypsum-sulphur formation" of Sicily and of the Italian mainland, although in Tuscany there are only traces of sulphur deposits.

Above the Mio-Pliocene sediments are pluvial terraces, equivalent to the glacial sediments of higher altitudes and latitudes. In the extreme southeast they are interlayered with pyroclastic sediments belonging to the Roman comagmatic province. On top of both are recent calcareous tufa, still being deposited by hot springs.

Apart from some traces of Triassic volcanism in northwestern Tuscany, an intense period of magmatic activity begins with the upheaval of the Apennines. Leaving out of discussion the serpentinous, diabasic, and gabbroid rocks which, with their uprooted masses enclosed in the Argille scagliose, are a problem in themselves, the oldest phases are the granites, of about Miocene age. They are of fairly near-surface consolidation. The larger masses and batholiths are known only in the Tuscan Archipelago (Elba, Montecristo, Giglio); two small outcrops are found on the mainland (Gavorrano, Campiglia Marittima); but according to unpublished data granites are also known or supposed on valid grounds to underlie the present surface (say at depths of the order of one km) in other places in southwestern Tuscany. Genetically connected with the granites are the mineralogically famous pegmatites of Elba, the pyrometasomatic iron ore deposits of the same island, the telemagmatic tin deposits of Campiglia Marittima, and at least part of the huge iron pyrite deposits and of the minor copper lead and zinc deposits of Tuscany.

Among the acid effusive rocks, the liparites of Campiglia Marittima are still of undetermined age; some authors are of the opinion that they are contemporary with the granites, whereas others consider them post-Pliocene. Certainly of Quaternary age are the trachytes found farther southeast in Tuscany, which have their continuation in the belt of trachytes of Latium. Related to the trachytes, the main occurrence of which in Tuscany, in the huge flat dome of the Monte Amiata, are the famous cinnabar deposits (see for instance (2) and (10)); and most probably also the antimony deposits. Perhaps some insignificant lead and zinc outcrops also belong to the Quaternary magmatism.

The last actual manifestations of this endogenous activity are the dry emissions of carbon dioxide mixed with hydrogen sulphide ("putizze"), the numerous hot and mineral springs, and the marvellous sprouts of boric-acid-carrying hot steam called "soffioni."

THE ANTIMONY DEPOSITS.

Italy as an Antimony Producer.

While Italy has long been on the list of the world's antimony producers, the history of production is not as complete as might be desired. For the pre-

decessor states of the present nation, relevant data are lacking; for united Italy, prior to 1904 the records give tonnage of ore but no average assays, and make no distinction between sulphide and commercial oxide.

Tuscany had become a producer by the early years of the nineteenth century but had disappeared from the list before the middle of the century; it entered the field again in the eighties, but faded away shortly before 1910; this has been attributed mainly to the drop in international price of the metal; but the nearing exhaustion of deposits, which seem to have very limited vertical extent, may also have played its part. Production was resumed during both World Wars and the second of these revivals is still going on, with a reasonably bright future.

The small and extremely erratic Sicilian production was limited to the second half of the past century.

Sardinia was the great newcomer in this field in the middle of the eighties and has since then kept its place without interruption.

TABLE I.

ITALIAN PRODUCTION OF ANTIMONY.

Metal contents of the *dressed* ore produced by the mines.

Year	Metric tons	Year	Metric tons	Year	Metric tons
1904	541.2	1920	238.5	1936	510.4
1905	649.8	1921	85.2	1937	567.0
1906	732.4	1922	181.2	1938	912.9
1907	921.3	1923	341.7	1939	635.5
1908	701.4	1924	468.0	1940	683.7
1909	541.2	1925	385.2	1941	889.2
1910	550.0	1926	447.2	1942	772.2
1911	360.0	1927	350.2	1943	612.0
1912	380.0	1928	286.5	1944	475.0
1913	270.0	1929	388.5	1945	378.0
1914	147.0	1930	402.8	1946	442.8
1915	860.0	1931	334.8	1947	510.4
1916	1072.5	1932	374.0	1948	558.6
1917	864.2	1933	366.0	1949	627.4
1918	510.0	1934	355.3	1950	678.2
1919	—	1935	468.0	1951*	649.2

* Provisional figures.

Table I, which was computed from 1904 until 1908 from official data and then from the statistics published by the Azienda Minerali Metallici Italiani (11), gives the metal content of the yearly production of dressed ore from the Italian mines; it therefore comes nearest to telling what we would like to know, namely the amount of antimony metal in any form taken out annually from the Italian soil.

For 1950 according to A.M.M.I., the metal content of the dressed ore from Sardinia was 494.96 metric tons, from Tuscany 183.26 metric tons, total 678.22 tons. Ore production outside these two regions was almost insignificant. The Sardinian ore yielded commercial products (metal, liquated sul-

phide, oxide) containing 424.51 metric tons of metal; Tuscan production, 140.25 tons of metal; total, 564.76 tons of antimony in metal form or contained in high-grade commercial products.

The Antimony Deposits of Tuscany.

Of the dozen or so known deposits in Tuscany (Fig. 1), scattered over an area of about 2,000 square kilometers, only half have had an output of real importance. They are, besides Poggio Fuoco, Tafone, and Montaùto, with which we will deal in greater detail, Casal di Pari and Pereta in Grosseto province, and the Cetine di Cotorniano in the province of Siena.

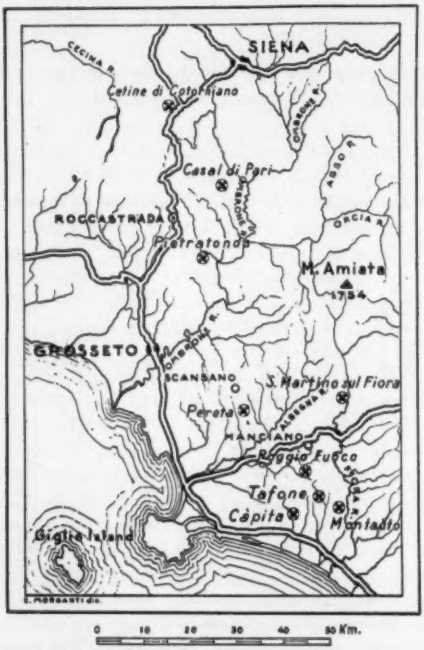

FIG. 1. Index map of the principal antimony deposits of Tuscany.

At present, only one of them is operating, the Macchia Casella mine, better known by the name Poggio Fuoco, used in the older literature. This mine and the old mines of Tafone and Montaùto form a natural group, all three situated within the township (*comune*) of Manciano in Grosseto province.

The Deposits of the Manciano Area.

The writer carried out, in 1950, an investigation involving geological mapping of an area of about 80 square kilometers within the township of Manciano

on the scale of 1 : 10,000; this area includes the Poggio Fuoco, Tafone, and Montaùto mines already mentioned. The investigation was made on behalf of the leaseholders, the A.M.M.I. (Azienda Minerali Metallici Italiani), an industrial group which is today practically the only antimony producer in Italy, both in Sardinia and on the mainland. The outcome of this study will

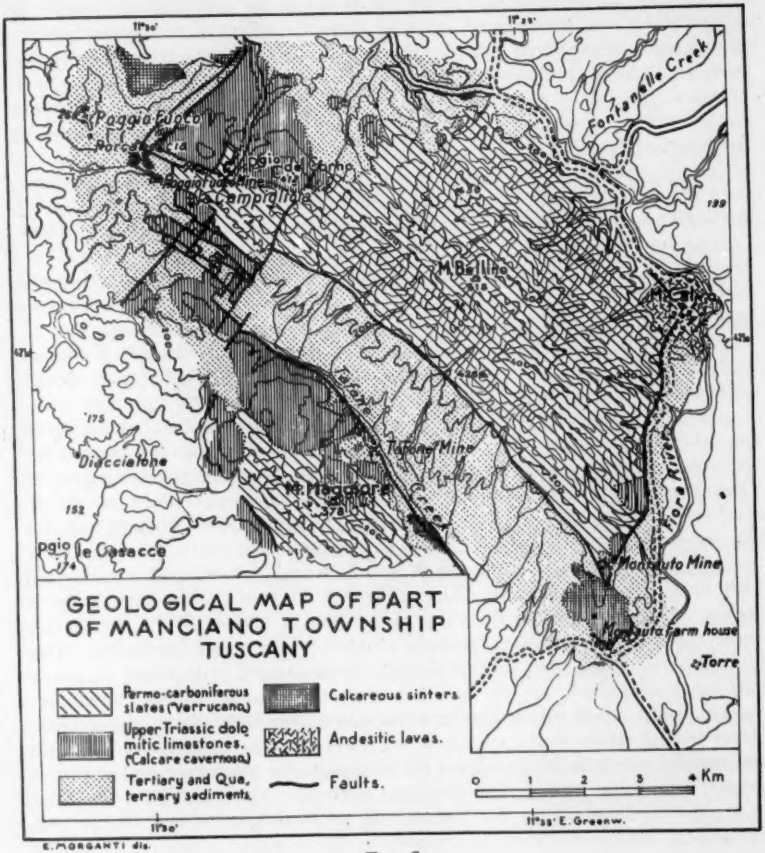

FIG. 2.

be published in full detail elsewhere (12). The main results are typical of the other Tuscan deposits and, if the data scattered in the literature have been interpreted correctly, of some other occurrences of the Mediterranean belt, such as several in Jugoslavia (9).

The geology of the area as sketched in the somewhat generalized geological map (Fig. 2) fits the pattern described in the previous pages. Two elongated

blocks bounded by steep northwest faults, and tilted to the northeast, are separated by a graben or perhaps by a mosaic of step-faulted blocks. One of the main faults of this system with which two of the major deposits of the area are associated, splits up, at least towards its western end, into a group of smaller parallel displacements.

A major north-south fault limits the blocks to the east, from the southeast corner of the area investigated as far as about the center of its eastern border; from here northward its place is taken by another northwest-southeast disturbance. At the intersection of the two faults is the small extinct volcano of Monte Calvo, one of the extreme outliers of the volcanic systems of Latium. In the extreme northwest of the area still another fault system, striking about northeast, is evident.

The Verrucano forms the bulk of the two uplifted blocks; on their northeast faces lies a shell of *Calcare cavernoso,* thinned and broken up by denudation; this shell may reach a maximum thickness of the order of one hundred meters.

The Jurassic and Cretaceous are missing. The older rocks are covered by Tertiary and younger formations, beginning with the Macigno (sandstone), in the topographically lower parts of the area where the soft young sediments have escaped denudation.

Poggio Fuoco.—The presently exploited section of the Poggio Fuoco or Macchia Casella mine is on and near one of the main northwest faults, shortly southeast of its intersection with a fault of a northeast set.

The ore, practically pure stibnite with its oxidation products and without any other accompanying ore minerals except traces of pyrite, is generally associated with and includes, in many cases, its own weight of quartzose gangue. This quartz is generally dark in color, hard and cryptocrystalline, so that it commonly resembles chalcedony; part of it preserves the structure and the brecciated aspect of the replaced Calcare cavernoso; elsewhere it has distinctly concretionary features. In places, it is full of vugs whose walls are covered with small colorless crystals. The quartz-stibnite association forms tabular bodies, which may reach a thickness of a couple of meters, at the contact between the cavernous limestone and the overlying impervious Tertiaries. This contact is either the one of original sedimentation, and in this case is nearly horizontal; or a fault contact, in which case it coincides with the fault plane over a height equal to the displacement along the fault plane; these fault-planes belong either to the system which comprises the main northwest fault and parallel minor faults forming a set of steps to its southwest, or to another less important system roughly orthogonal to them. The miner has, therefore, to explore all sides except the bottom of a set of roughly square blocks each moderately shifted vertically in respect to its neighbor. Their dimensions may be of the order of a score of meters or even of only a few meters.

On the side where the quartz bodies are in contact with the dolomitic limestone, the limestone is often strongly silicified, with preservation of its original features. The silicification of the limestone gradually decreases and disappears farther away from the contact and so does the mineralization, although isolated clusters of stibnite may sometimes be found at any depth within the *Calcare cavernoso.* Very rarely traces of barite are associated with the quartz

gangue. Towards the impermeable Tertiary sediments the quartz sheets generally end abruptly, with the interposition of a few decimeters of a very dark clayey gouge, which obviously is a residual product of the dissolution of the limestones. There are a few open solution cavities, although they are far less conspicuous or genetically important than those in the quicksilver mines of the same metallogenic province.

The gouge also in places contains stibnite in small, rounded, very pure nodules. The mineralization rarely extends beyond the gouge though exceptionally it may go a little higher up, if the Tertiary cover consists not of compact sandstones or clays, but of a variety of the Macigno sandstone which either was originally porous or has become so through the solvent action of the mineralizing solutions. In this case silicification and even ore deposition may also have affected the lower beds of the Macigno, but this dispersion of the mineralization is by no means beneficial from a practical point of view.

Part of the ore is oxidized to hydroxides and hydrated antimony-calcium compounds (hydroromeite (8)); about half the run-of-mine is oxidized material, a consideration which is of metallurgical interest but has no bearing on the genesis of the primary ore.

The mineralization, then, is associated firstly with the normal contact between Tertiaries and *Calcare cavernoso,* a contact that does not go to depth because at Macchia Casella the Tertiaries form only a small island on the older rocks; and secondly with those portions of the faults which bring the two formations into contact. These two limitations reduce to perhaps two scores of meters or so, the maximum depth to which the mineralization may extend. Moreover, the physico-chemical conditions required for the deposition of the ore may also have been restricted to a very limited vertical range in this kind of epithermal subvolcanic deposit.

From the old mine workings the mineralization presumably continues along the main fault to a point near the Porcareccia farm where it meets the other, northeast striking, fault. That this second fault is ore-bearing, is definitely established by outcrops and by some underground exploration. Other traces of mineralization are known in connection with minor faults, all of northwest strike, within an area of about three square kilometers; this area stretches between the great fault of the mine, and what is probably an extension of the equally important parallel fault which forms the southwestern boundary of the Tafone graben.

A few meters from the intersection of the two main ore-bearing faults at the Porcareccia farmhouse, there is a spring of lime-bearing, encrusting water; and, farther away to the north of the mineralized area, conspicuous terraces of calcareous sinter.

From this description the conditions of the localization of the ore-deposition should be evident: silica- and antimony-bearing waters have risen along steep fault planes belonging to several fault systems, and at the contact between the fractured dolomitic limestone and the impermeable Tertiary sandstones and clays they have been dammed up and forced to abandon their mineral load.

Summarizing the position of the Poggio Fuoco occurrence: it lies on the northwestern extension of a major tectonic disturbance, the northwest striking

Tafone graben, on the important fault which limits this graben to the northeast; it extends from this main fault through minor parallel faults to the southwest, just inside the extension of the graben. The Poggio Fuoco deposit moreover lies near the meeting point of the Tafone Valley disturbance with another, more local, fault system striking at right angles to it.

Tafone.—Following the Tafone graben from the Poggio Fuoco deposit to the southeast about six kilometers, we find the site of the once renowned Tafone mine, which lies near the opposite, southwest boundary fault of the Tafone plain. Very little can be seen today of this occurrence, whose exploitation in olden times and re-exploration today have been tremendously hampered by the shallow water table ubiquitous in the extremely permeable sediments of the bottom of the valley.

The deposit once exploited lies in the plain near the line along which it meets the abrupt slope of the hill to the southwest; the foot of the slope corresponds roughly to the trace of the great fault which cuts the northeastwardly tilted southern block of Verrucano with its thin discontinuous veneer of dolomitic limestone. The throw is not very big: electric and seismic refraction investigations have located the top of the Verrucano, on the downthrown side below the plain, where it is covered by the Argille scagliose, at about sixty meters below the surface. The rounded blocks of pure stibnite which, according to reports a century old, were strewn by the hundreds on the surface of the ground within a distance surely less than a hundred meters from the slope and fault, and formed the wealth of the mine, were perhaps weathered out from the Argille scagliose.

The exact features of this deposit, which seems to differ in many details from all the others of Tuscany, are unknown as yet; a drilling program is just under way. Leaving out of consideration the difference in size—a few centimeters in one case, decimeters in the other—the rounded blocks of pure granular stibnite of the old Tafone mine have many similarities with the nodules encountered, for instance, at Poggio Fuoco, as concretions within the clay gouge in the immediate vicinity of the main ore-bearing quartz bodies.

Also not far from the Tafone mine there are deposits of calcareous tufa, although of very limited extent.

Montaùto.—Still farther to the southeast along the Tafone graben is a point beyond which it can no longer be followed as an independent morphological feature, as it merges with the great plain covered by volcanic products and calcareous sinters which marks the beginning of Latium. In the area under consideration the volcanic plain is roughly limited on its western border by the Fiora River, which with its southerly course near the eastern foot of the great northern Verrucano block clearly follows a very important fault line of enormous throw.

Where this north-south fault line cuts the northwestern fault which forms the northeastern border of the Tafone plain, is the third antimony deposit of the Manciano area, exploited in remote times by the old mine of Montaùto. Five kilometers approximately to the north, where the huge north-south fault again meets a northwestern disturbance, stands the small isolated volcanic outlier Montecalvo, with its andesitic lavas. At Montaùto itself there is an

extensive cover of calcareous sinters occupying an area of about one square kilometer; these sinters are the product of a formerly intense thermal activity, the last remnants of which are several smaller encrusting springs; some of them carry carbon dioxide and hydrogen sulphide; one which flowed for some time from a prospecting trench had a temperature quite above normal.

The geology of the mineralized tract is only partly accessible to surface investigation, as the interesting formations are for the greater part hidden by the calcareous sinter shell, by volcanic tufa, by old mining dumps, and by such impassable, thorny jungle as one would never expect to meet in Europe. Still the general features are the usual ones, namely, a basement of Verrucano slates supporting a shield of the Calcare cavernoso dolomitic limestone, covered in its turn by Argille scagliose and Mio-Pliocene sediments; and between limestone and Tertiaries, a concretionary quartz sheet containing the stibnite. That we are near the meeting point of two very important fault lines is proved beyond doubt by the general geological mapping, even though the exact positioning of the faults within the mineralized area will have to wait for fresh mining activities. Former mining was on the ore bodies along the very moderately dipping stratigraphic contact between the limestone and the Tertiary clays; and as these clays within the old mining area are almost completely eroded, the ore was taken practically from the surface.

Two points deserve special mention: the first is the localization of the Montaùto deposit at the crossing of two main fault lines striking respectively northwest and north-south. Both strikes have an enormous tectonic importance in the whole central segment of the Italian peninsula; the first, being parallel to the elongation of the Peninsula itself with its mountain backbone, the Apennines, is called the "Apenninic strike." As noted by Trevisan [4] the tips of the southward pointing wedges enclosed between faults belonging to these two main systems, are throughout Tuscany preferred points for displays of endogenous activity like old volcanoes, ore deposits, "soffioni," thermal and mineral springs, and gas emissions ("putizze").

The other point is that both in Poggio Fuoco and in Montaùto, where there are fairly rich mineralizations, the thickness of the dolomitic limestone shield is below average. Although the number of cases considered is too small for application of statistical rules, it seems possible that a reduced thickness of the limestone may limit the dispersal of the mineralizing solutions in it, and therefore may favor higher metal concentrations in its roof.

Other Mineralization.—About one and one-half kilometers west-south-west of the Poggio Fuoco mines, and a few hundred meters from minor stibnite occurrences and from a tiny "putizza" (gas emission), small quartz-veinlets and impregnations carrying specks of galena, sphalerite, and chalcopyrite occur in the Tertiary Macigno sandstone. The author would attribute them to the same metallogenic epoch as the stibnite deposits.

More frequently, at several places in the area there are barite-limonite mineralizations—the limonite being clearly an oxidation product of pyrite

[4] Verbal communication of Trevisan to the writer, who gratefully acknowledges the permission to give publicity to a subject on which Trevisan himself has a detailed paper in preparation.

with occasional arsenopyrite—at the footwall of the Calcare cavernoso, between it and the underlying Verrucano. Only once has stibnite been found associated with the limonite. The author believes, admittedly on rather scanty evidence, that the mineralization originated from what we may broadly call the same solutions which were the carriers of the stibnite. Conceivably chemical action of the limestone, together with the drop in temperature and pressure, might have been responsible for the fact that pyrite was deposited at the footwall, and stibnite at the roof of the limestone itself; alternatively the pyrite belongs to a slightly earlier, higher-temperature period. There is an interesting analogy to Yellow Pine, Idaho, where White (*7*) likewise believes that the pyrite and the stibnite mineralizations may be in close genetic relationship.

The Other Tuscan Occurrences.

Although the author studied only the Manciano region in detail, he is acquainted with most of the other Tuscan antimony occurrences as a result of short visits.

Most similar to Poggio Fuoco and Montaùto is the once very important Casal di Pari deposit; there also the stibnite and its oxidation products are associated with quartz gangue and are found at the contact between the Calcare cavernoso and the overlying Argille scagliose; the moderately thin layer of Calcare cavernoso lies on the Verrucano slates. The old mine is about one kilometer to the south of the gas emissions and hot thermal springs of Petriolo, located in their turn at the meeting point between a very important north-south striking fault and a disturbance coming from the west. However, according to scanty and seemingly not very accurate old reports, the ore at Casale di Pari, besides being localized at the roof of the Calcare cavernoso, also penetrated for some distance into this dolomitic limestone itself.

A mine that was reopened in 1938 and worked until almost the end of the Second World War is the Cetine di Cotorniano near Rosia and not far from the provincial capital of Siena. Here again a cliff of Calcare cavernoso rests on the Verrucano basement and bears a scanty cover of Argille scagliose. Here the ore, pure stibnite and its alteration products practically without any other metallic impurities, is as usual included in quartz sheets and extensive silicified zones, which in this deposit however occur at the footwall and not at the roof of the exceptionally thick dolomitic limestone. A limited production also came from brecciated veins which rise vertically into the limestone for a restricted height from its footwall.

There is only one more antimony occurrence in Tuscany which has had any real past importance—the mine called variously Pereta or Zolfiere, in Scansano Township (*comune*); it is mentioned also by Lindgren (*6*). The old underground workings unfortunately are no longer accessible on account of the continuous deadly flow of dry poisonous gases, hydrogen sulphide, and carbon dioxide which have invaded the whole mine and seep from its mouth. These gases deposit not only elemental sulphur in such quantity that in times of dearth it has been worth exploiting for local agricultural consumption; but also, on the walls of the old workings, veils of cinnabar and small needles of

stibnite. From the dumps it appears that the ore is in a gangue of quartz sometimes crystallized and sometimes of concretionary and of "pot-sherd" appearance, and that the mineralization must be at or near the contact of Macigno sandstone and other Tertiary clayey rocks, on an underlying limestone; this limestone however is almost certainly not the Triassic Calcare cavernoso, but of far younger age. In this connection it may be recalled that limestones are found at several levels in the stratigraphic column; the whole Mesozoic, from the Calcare cavernoso upwards, is almost exclusively calcareous, and the Argille scagliose contain inliers, which may reach considerable size, of the Alberese and Palombino limestones; the nummulitic limestones at the bottom of the Macigno have already been mentioned. The ore bodies, as far as one can guess from old reports, seem to have the form of steeply dipping ore shoots emplaced on a great north-south striking disturbance. At a couple of kilometers from the antimony deposit is the working cinnabar mine of Cerreto Piano.

An occurrence that was worked on a small scale during the eighties, but is now being explored again, is S. Martino sul Fiora, about 25 kilometers to the north of the Montaùto deposit; it likewise lies on the western bank of the flood-plain of the river Fiora, and this bank in both localities more or less follows a fault scarp, sometimes steep and sometimes flat, belonging to the north-south system. At S. Martino a mass of hard subcrystalline Liassic and Jurassic limestones, covering a surface of less than one-half square kilometer, rises steeply to a height of about 200 meters above the level of the river plain, amidst the chaotic clays of the Argille scagliose formation; it looks like a splinter from the deeper autochtonous Mesozoic, which may have pierced the soft overlying sediments.

The locus of the mineralization here is the very steep eastern contact surface between the limestones and the Argille scagliose; this surface has a strike which lies between the two main north-south and northwest tectonic directions, and surely follows the great north-south fault very closely. It is worth noting that the part generally played by the Triassic dolomitic limestone is in S. Martino sul Fiora taken instead by the Liassic limestone, which is very similar to the Calcare cavernoso in its mechanical behavior and also hydrologically.

In S. Martino the silicification of the contact is much reduced, and stibnite impregnates the limestone and clays in the immediate vicinity of the contact itself. There are also a certain number of small nearly vertical mineralized fissure veins, a few centimeters thick, in the limestone near the contact, and here in association with the mainly calcitic gangue there is also some fluorite. The presence of this mineral and the scarcity of quartz give this deposit a somewhat "cooler" character than the others of the area. Old reports of the presence of traces of silver ores here must await confirmation by the new exploration.

Scarcely more than three kilometers to the east of the S. Martino deposit, on the other side of the Fiora valley, is Monte Rosso, a small extinct volcano belonging to the Roman volcanic province; its products were tephritic lavas.

In Tuscany stibnite showings, although of minor economic interest, are also associated with the contact of the nummulitic limestone of Oligocene age, at the base of the Macigno sandstone complex, with the overlying impervious formations. Finally, as already hinted, there may also be stibnite mineralization between the Alberese and Palombino limestones and the Argille scagliose which surround and contain their detached masses.

The structure previously described in the Manciano area repeats itself south of the mapped area. Fault blocks of Verrucano carrying younger formations on their tops are tilted to the northeast and separated by steep faults striking northwest. Probably connected with such a structure, and five to six kilometers to the southwest of the Tafone valley, is the mineral deposit of Càpita, which follows the familiar Verrucano–Calcare cavernoso–Argille scagliose pattern; its point of special interest however is that cinnabar in fair amounts is associated with the stibnite.

ORIGIN OF THE TUSCAN ANTIMONY DEPOSITS.

The discussion of general characteristics of the antimony deposits of Tuscany, and their localizing structural features, leaves something to be said about the origin of the solutions which brought in the mineralization.

First, a few more words on the mineralogy of these deposits may throw light on the character of the ore solutions. As stated, the gangues are quartz, sometimes accompanied by traces of barite and fluorite; the ever present calcite and dolomite are probably derived from the country rock, and the locally abundant gypsum is supergene. The only ore mineral found in quantity is stibnite, with its weathering products (oxides, hydroxides, hydrous calcium antimoniates, oxysulphide). Besides the pyrite and marcasite often present but always in very small quantities, all the other ore minerals are in extremely scanty traces only; among them, the least rare is cinnabar; realgar is reported in a couple of instances, and a realgar-orpiment mineralization was once discovered about six kilometers to the northeast of the antimony occurrence of S. Martino sul Fiora and very near to one of the mercury mines. Berthierite was found at Pereta, but was tentatively explained as being due to a local interaction between stibnite and the weathering products of marcasite (8); traces of silver in the ore were reported from Casal di Pari and S. Martino. Elemental sulphur, sometimes in considerable quantities, seems due partly to the weathering of the stibnite and partly to oxidation of the H_2S from the gas seepages.

The presence of cinnabar constitutes additional evidence in favor of the close relationship between the cinnabar and the stibnite occurrences of Tuscany. It is true that deposits where both ores occur together, not only in strict association but also in comparable quantities, are scarcely known. But in many of the occurrences of one of them the other has been found also, at least in traces. And the deposits of both are located in the same area and in many instances at very short distances apart. The conclusion is that, although a slight difference between the optimum physico-chemical deposition conditions of each of them has caused their localization in separate even if neighboring

deposits, the mineralizing solutions must have a common origin, and practically the same age and the same history.

On the whole it seems that the cinnabar deposits are limited to the more immediate neighborhood of a central focus, which is the huge trachytic dome of Monte Amiata. To the same deeper center which produced this trachyte the origin of the cinnabar and stibnite mineralizations is ascribed by almost universal consent. An additional clue is supplied by the common, extremely young age both of the Monte Amiata trachyte (Quaternary) and of the cinnabar and stibnite occurrences which sometimes are deposited in, or localized just below, Pliocene sediments. There is evidence that the disturbances which supplied the channels for the rising fluids are at least in part Quaternary; and thermal springs, gas emissions, and even ore deposition are going on even today under our eyes.

THE FUTURE OF ANTIMONY MINING IN TUSCANY.

Regarding the industrial future of the Tuscan antimony deposits, a discouraging feature is the probably very small vertical extension of the mineralization; we have no proven data on this point, but we may guess it to be of the order of 50 meters. This carries as a consequence, firstly, that no single deposit can be supposed to harbor great reserves, and secondly, that there is a good chance that many deposits may have been either partly or wholly eroded away. Conversely they may still be hidden under a cover, even if a thin one, of impervious sediments without any revealing sign showing at the surface.

But the last remark also has an encouraging implication: the fairly widespread character of the antimony mineralization of Tuscany raises the hope that there may still be concealed deposits as yet unknown; the increasing understanding of the laws governing their localization justifies the expectation that we may find the key for opening them up and making them amenable to exploitation.

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SERVIZIO GEOLOGICO,
ROME, ITALY,
Dec. 3, 1951.

Since the foregoing was written new exploration results at the old Tafone mine have been made available through the kindness of the A.M.M.I. industrial group. By April 30, 1952, over 40 bore holes, totaling about 1000 m, have been drilled in an area about 500 by 100 m near the old mine. The borings disclose that the Tafone deposit is of the conventional type, i.e., the Argille scagliose are underlain by horizontal Calcare cavernoso, which in one hole has a thickness of 40 meters. The Calcare cavernoso in turn rests on Verrucano, and most of the ore lies at the contact between Argille scagliose and Calcare cavernoso, extending for a few meters into the latter. The rounded blocks of stibnite, previously referred to, turn out to be extreme outliers of the ore. The mineralizing fluids penetrated the impervious clay cover somewhat higher than in most places, due to the stronger mineralization, and presumably also taking advantage of small limestone beds within the clays. The writer believes that the clays containing the stibnite blocks belong wholly or partly to the Argille scagliose horizon.

About 25 holes have encountered the ore bed at depths of 3 to 16 m, and have established the ore bed, to be 3½ to 20 m thick, with an average content of 5% Sb. Conservative estimates indicate assured reserves of 6000 tons of antimony up to date, and is still progressing. In contrast, the total production of the more important deposits of Tuscany has been of the order of perhaps 1500 to 2000 tons.

The ore is so soft, that good cores are rare. The stibnite is generally quite pure, but in places it is accompanied by granular pyrite. The drilling has also disclosed bits of marcasite alternating with thin bands of antimonite, strongly reminiscent of the well-known "Schalenblenden." Quartz is scarce or absent, and the deposit appears to have been formed at somewhat lower temperatures than the others already described.

The discovery is due to the perseverance of the director of the antimony mines of the Manciano area, P. Principato.. When further drilling and conventional underground exploration will have supplied additional information, he will publish a full report in the Italian mining journal "L'industria mineraria."

G. DESSAU

ROME,
May 1, 1952.

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INDICATOR MINERALS, COEUR D'ALENE SILVER BELT.[1]

THOMAS W. MITCHAM.

CONTENTS.

PAGE

Abstract 414
Introduction 415
Geologic setting 416
General considerations 419
Minerals of the Coeur d'Alene district 422
Mineral constituents of the Beltian sediments 422
General discussion 422
Indicators among Beltian minerals 425
Major minerals 425
Accessory minerals 426
The basic dike minerals 427
The hydrothermal vein minerals 427
Paragenetic features 427
Bleaching alteration stage 429
Carbonate-quartz stage 433
Ore minerals of the sulfide stage 439
General description 439
Arsenopyrite 439
Sphalerite 442
Tetrahedrite 442
Chalcopyrite and pyrite 443
Galena 444
Gangue minerals of the sulfide stage 445
General description 445
Spatial distribution of chlorite 446
Time relationships of chlorite 448
Chlorite, a possible indicator 448
Summary of genetic types of chlorite 449
Bibliography 449

ABSTRACT.

Deeply buried, high-grade oreshoots in carbonate-quartz veins are found in the Silver Belt of the Coeur d'Alene district by the application of various geologic criteria. Exploration is costly, and additional indications of the proximity of ore are highly desirable. The purpose of this study is to examine significant mineralogical features of the district in an attempt to develop additional helpful criteria.

A search is made for indicator minerals; i.e., minerals, the spatial distribution of which may be indicative of the position of ore. In this respect,

[1] Submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Faculty of Pure Science, Columbia University.

the spatial distribution patterns of most of the vein and country-rock minerals are discussed, and the genesis and time relationships of the minerals are interpreted as an aid in the evaluation of these patterns.

Arsenopyrite is believed to be an indicator, apparently forming envelopes around oreshoots. Similarly, late hydrothermal chlorite is considered to be an indicator. Sericite and carbonates of pre-hydrothermal-vein origin have a negative significance as indicators; i.e., little ore has been found in areas where these minerals are concentrated. Since beds rich in detrital quartz are the best ore horizons, such quartz is considered to be an indicator of limited practicability.

An attempt is made to clarify the genetic classification of the various minerals, and within genetic types a few minerals not previously described in the district are listed. Six genetic types of chlorite are defined.

The hydrothermal-vein history of the district is divided into three stages. In chronological order these are: (1) the bleaching alteration stage, (2) the carbonate-quartz stage, and (3) the sulfide stage. The hydrothermal bleaching alteration of large areas of the country-rock is largely the destruction of the rock pigments, and no strong sericitization is involved as previously thought.

INTRODUCTION.

The Silver Belt Problem.—This mineralogical survey is largely concerned with spatial distribution of most minerals that occur in the Silver Belt of the Coeur d'Alene mining district. The objective is to seek those minerals that have distribution patterns indicative of the position of oreshoots. To aid in determining spatial distribution patterns, investigations of the deposition sequence, textures, and the nature of occurrence of the minerals are made. Every mineral in place in the Silver Belt is considered with the exeception of those in the shallow oxidized zone, which is at present poorly accessible.

Although this study is directed to the Silver Belt area, it cannot logically be isolated from its district setting. Some studies were made both in other areas of the district as well as beyond district boundaries. Similarly, many of the conclusions reached may apply to the Coeur d'Alene district as a whole.

Since the topography consists almost entirely of steep slopes, and geologic details are largely concealed by thick soil and forest, tunnels have been frequently used for shallow exploration. These and deeper workings have exposed numerous carbonate-quartz veins. The tops of rich silver oreshoots found in some of these veins may lie as much as 4,000 feet below the surface. The discovery of such oreshoots presents difficult problems. Exploration criteria used by district geologists have been thoroughly discussed by Sorenson (28).[2] In this study, it is hoped to contribute additional criteria in the search for "blind" oreshoots.

Methods of Study.—The field work was started in June, 1949. Since that time, four and a half months have been spent in the field making observations and collecting samples. A large part of the balance of the intervening two years has been devoted to laboratory study.

Some 759 samples from the properties of six operating mining companies in the Silver Belt and a few scattered samples from other areas of the Coeur d'Alene district were collected and studied.

[2] Numbers in parentheses refer to Bibliography at end of paper.

Laboratory techniques used have included microscopic study of thin-sections and immersion mounts, thermal analysis, X-ray powder patterns, heavy media separation, magnetic separation, elutriation, qualitative and quantitative chemical analysis, electron microscope photography, and porosity determinations. Volume percent determinations were made by means of a grid ocular and with an estimated relative error of 5–10 percent. The quantitative chemical analyses were made by Ledoux and Company and the electron microscope photographs by the Electron Microscopic Laboratory of Columbia University. In the course of the work, 460 thin-sections, 298 thermal analyses, and a number of X-ray powder patterns were made and studied.

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A project of this scope would have been most tedious, indeed, if the accumulated knowledge of mining geologists and engineers of the companies concerned were not used to full advantage. The writer is greatly indebted to these men who indoctrinated him in a modern version of the geology and the problems involved in ore-search in the Silver Belt. In this respect, the following have been particularly cooperative: C. P. Pollock, W. R. Landwehr, L. H. Hart, Keith Whiting, M. W. Cox, and P. I. Conley, geologists of the American Smelting and Refining Company; R. F. Robinson and James Quinlin, geologists, and Robert Anderson and James Durham, engineers, for the Sunshine Mining Company; and R. E. Sorenson, Kenneth Baker, and M. W. Hutchison, geologists of the Hecla Mining Company. However, these men do not necessarily concur in the author's conclusions.

The base geology on mine maps shown in this paper is derived from maps of the cooperating mining companies.

GEOLOGIC SETTING.

Except for isolated remnants of Tertiary gravels, the only exposed sedimentary rocks are the Algonkian Belt series which is at least 26,000 feet thick (35). The section, originally comprising shallow water muds and sands throughout, was subdivided by Ransome and Calkins (21). With progressive minor changes, it has been described numerous times in the literature, the latest being by Sorenson (28c). From oldest to youngest the divisions defined by Ransome and Calkins and the thicknesses given by Sorenson are Prichard (12,000 ft), Burke (1,800–2,400 ft), Revett (2,100–3,400 ft), St. Regis (1,000–2,000 ft), Wallace (4,500–6,000 ft), and the

Striped Peak (1,500 ft). The rocks are mainly argillites and quartzites but carbonatites are found at some horizons.

Into this thick series of Algonkian sediments, monzonitic stocks and dikes of monzonite, lamprophyre, and diabase were intruded, these being minor in areal extent (Fig. 1).

The Coeur d'Alene district is characterized by complex folding and faulting. Whiting (35) gives a concise reconstruction of the major structural events:

1. Development of a broad NE-trending anticline accompanied by/or immediately followed by monzonitic intrusives on the south flank.
2. Folding, trending north, and swinging to east in the southern area.
3. Faults, developing on the same trend as the second folding, e.g., the Dobson Pass fault with a normal displacement of 8,000 feet.
4. E–W series of faults displacing older faults.
5. Thrust faulting from west to east, e.g., the Carpenter Gulch fault.
6. The major Osburn tear fault with a horizontal component of 10–15 miles (9d), this being accompanied by/or immediately followed by the intrusion of diabase dikes and the introduction of ore depositing solutions (lamprophyres are about this age also).

The ore deposits of various areas of the Coeur d'Alene district are rather distinctive. Gold-tungsten, lead-silver-zinc, zinc, copper, antimony, and silver ores are found. Many of the same ore minerals are found in the various deposits, but their abundance in different types varies sharply.

An area where the most valuable mineral of the ores is argentian tetrahedrite is called the Silver Belt (formerly the Dry Belt). It is bounded on the north by the Osburn fault and on the south by the Placer Creek fault, and lies between the town of Wallace on the east and the Crescent Mine on the west (Figs. 1 and 2). Clark (4) wrote that the Dry Belt was ". . . the dullest part of the district . . . ores there are distinct from all other parts of the district, being almost uniformly of the dry class, either gray copper or carbonate with little value outside of silver." He did point out that the Yankee Group (now the Sunshine) was richer in silver. This attitude persisted for some time, but the annual silver production of probably less than 5,000 ounces in 1900 rose rather steadily to over 1,000,000 oz in 1927 and to 13,971,196 oz in 1937, when the Sunshine mine was the world's largest producer of silver (27).

The richness of some of the Silver Belt oreshoots is illustrated by the Silver Syndicate oreshoot, which was discovered about 3,700 feet below the surface and averaged at that elevation: 21.7 percent lead and 46 ounces of silver per ton with a 210-foot strike length and a width of 4.3 feet (Sunshine Mining Company report for 1946).

Rasor (22) and Gale (7) have discussed the geology of parts of the Silver Belt. Shenon and McConnel (27) made a comprehensive study and published a plan map on a scale of 1 :12000. Recent accounts of the geology have been given by Sorenson (28) and Robinson (24). The outstanding feature of the area is a down-thrown block between the Osburn and the Big Creek faults (Figs. 1, 2, and 3) which has been compressed into the major

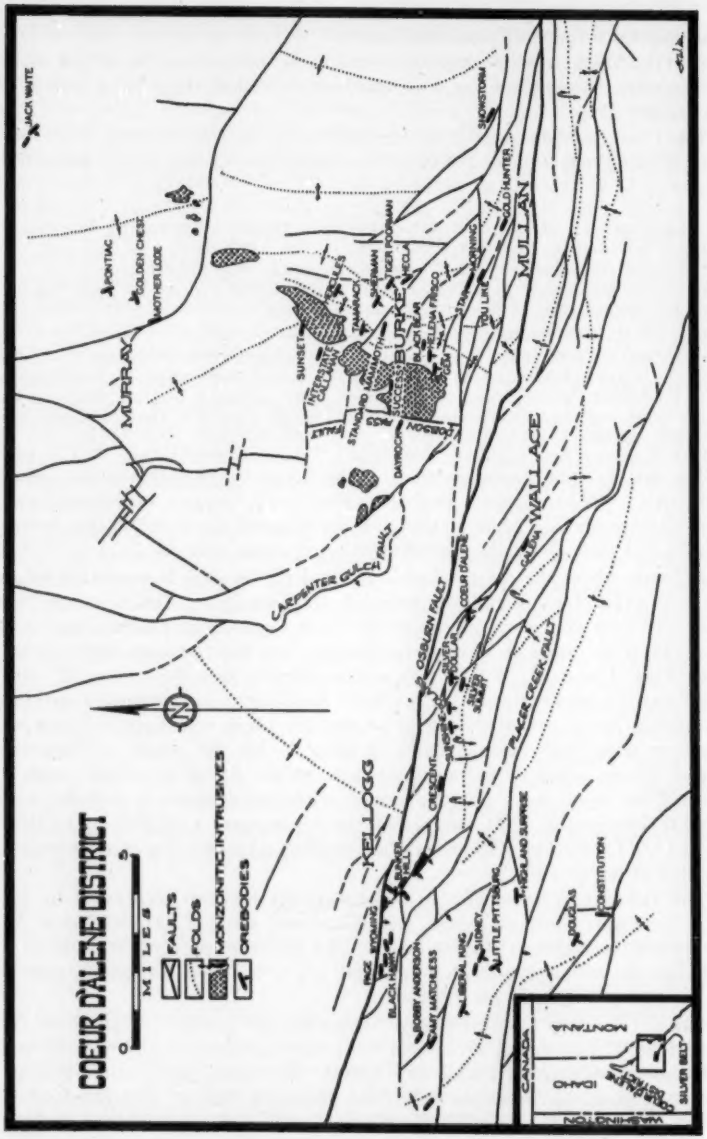

FIG. 1. Plan map of Coeur d'Alene district modified from Whiting (1940).

Big Creek overturned anticline and into the large syncline between the Polaris and Osburn faults. The limbs of this syncline and the north, generally overturned limb of the Big Creek anticline are crumpled into minor folds, some of which are illustrated in Figure 13, the entire area of which is located on the north limb of the anticline. This folded block is shattered by major E-SE-trending, normal and reverse faults, e.g., the Polaris and Silver Syndicate faults. Carbonate-quartz replacement veins occur along these faults and on minor E and E-NE shears along them. In and on these veins the silver-rich oreshoots of large pitch occur.

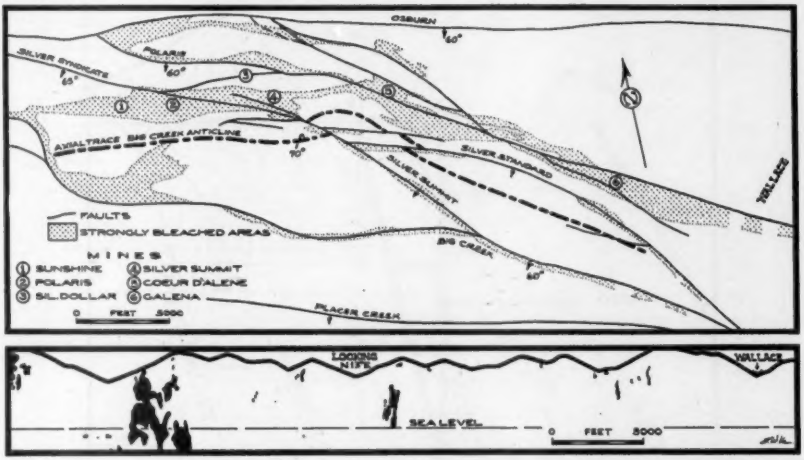

FIG. 2. Plan and generalized vertical longitudinal projection of the Silver Belt. Plan is at an elevation of 2,750 feet—after Shenon and McConnel (27) and Sorenson (28c). Vertical projection shows most of the Silver Belt oreshoots—modified from Sorenson (28a).

GENERAL CONSIDERATIONS.

The term "indicator mineral" is herein applied to a mineral whose distribution outside an ore body is such as to furnish a clue to the position of that ore body.

In establishing a mineral as an indicator, the following postulates are made:

1. The spatial distribution pattern of the mineral in question relative to ore bodies must be significant.
2. The distribution pattern and genetic relationship should have a relative constancy in the area studied.
3. If the pattern is too large or too small, the indicator lacks practical precision.
4. A mineral closely associated in time of deposition is most likely to have spatial significance. The same host solutions are likely to be involved and the same generation of openings is likely to be available for the deposition of the indicator and the ore. Indeed, the indicator may be an ore mineral.

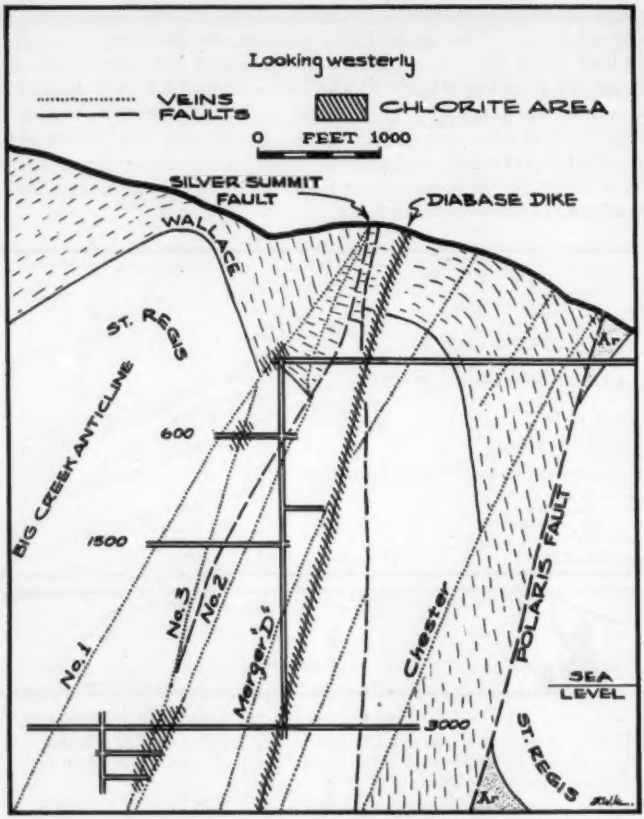

FIG. 3. Cross section through the Silver Summit mine. Areas of chlorite occur in and near ore on the lower levels, above ore on the upper levels, and in the diabase dike. (Ar) Revett formation. Base section is after Sorenson (28c).

5. The ultimate test in establishing a mineral as an indicator is its successful utilization as a factor in the search for ore.

The Silver Belt minerals have been examined in the light of the above considerations. Since it is established that Silver Belt ore bodies are shoots within carbonate-quartz veins, all vein minerals could be designated as indicators. However, the difficult problem in that area is the determination of what points in veins may contain oreshoots rather than the search for veins. Consequently, in this study only those vein minerals indicative of the position of oreshoots in veins are considered to be indicators.

TABLE 1.

MINERALS IN PLACE, COEUR D'ALENE MINING DISTRICT. THE FIRST RECORD IN SCIENTIFIC LITERATURE OF THE OCCURRENCE IN THE DISTRICT OF EACH MINERAL IS SHOWN. 108 DIFFERENT MINERALS ARE LISTED.

Minerals of the Algonkian sediments (pre-hydrothermal-vein)			
Ankerite	Hobbs, et al (1950)	Leucoxene	Ransome and Calkins (1908)
Biotite	Ransome and Calkins (1908)	Magnetite	Ransome and Calkins (1908)
Calcite	Lindgren (1903)	Muscovite	Ransome and Calkins (1908)
Carbonaceous matter	Ransome and Calkins (1908)	Pyrite	Ransome and Calkins (1908)
Chlorite	Ransome and Calkins (1908)	Quartz	Clayton (1888)
Dolomite	Ransome and Calkins (1908)	Rutile	Ransome and Calkins (1908)
Feldspar	Lindgren (1903)	Sericite	Lindgren (1903)
albite		Titanite	
orthoclase		Tourmaline	Lindgren (1903)
microcline		Zircon	Ransome and Calkins (1908)
Hematite	Ransome and Calkins (1908)		

Minerals of the monzonitic intrusives			
Allanite	Anderson (1949)	Plagioclase	Ransome and Calkins (1908)
Apatite	Ransome and Calkins (1908)	albite	Anderson (1949)
Biotite	Ransome and Calkins (1908)	Pyrite	Ransome and Calkins (1908)
Chlorite	Ransome and Calkins (1908)	Pyroxene	Ransome and Calkins (1908)
Epidote	Ransome and Calkins (1908)	Quartz	Ransome and Calkins (1908)
Hornblende	Ransome and Calkins (1908)	Sericite	Ransome and Calkins (1908)
Kaolinite	Ransome and Calkins (1908)	Titanite	Ransome and Calkins (1908)
Magnetite	Anderson (1949)	Zircon	Anderson (1949)
Microcline	Ransome and Calkins (1908)	Zoisite	Anderson (1949)
Orthoclase	Ransome and Calkins (1908)		

Minerals of the lamprophyre and diabase dikes and their immediate walls			
Apatite	Ransome and Calkins (1908)	Orthoclase	Ransome and Calkins (1908)
Augite	Jones (1919)	Pennine	Hershey (1912)
Biotite	Ransome and Calkins (1908)	Plagioclase	Ransome and Calkins (1908)
Calcite	Ransome and Calkins (1908)	albite	Jones (1919)
Chlorite	Ransome and Calkins (1908)	labradorite	Jones (1919)
Diopside	Shannon (1919) (3)	Quartz	Ransome and Calkins (1908)
Epidote	Ransome and Calkins (1908)	Rutile	Shannon (1919) (3)
Hornblende	Ransome and Calkins (1908)	Soapolite	Ransome and Calkins (1908)
Ilmenite	Ransome and Calkins (1908)	Sericite	Ransome and Calkins (1908)
Kaolinite	Ransome and Calkins (1908)	Serpentine	Ransome and Calkins (1908)
Leucoxene	Ransome and Calkins (1908)	Talc	Ransome and Calkins (1908)
Olivine	Jones (1919)	Tridymite	Shannon (1919) (3)
Opal	Shannon (1919) (3)		

Contact-metamorphic minerals			
Andalusite	Ransome (1908)	Hedenbergite	Umpleby and Jones (1923)
Amphibole	Ransome (1908)	Magnetite	Umpleby and Jones (1923)
actinolite	Umpleby and Jones (1923)	Muscovite	Ransome (1908)
Biotite	Ransome (1908)	Olivine	Umpleby and Jones (1923)
Chlorite	Umpleby and Jones (1923)	Sericite	Umpleby and Jones (1923)
Diopside	Ransome and Calkins (1908)	Sillimanite	Ransome (1908)
Epidote	Umpleby and Jones (1923)	Titanite	Ransome and Calkins (1908)
Feldspar	Ransome (1908)	Vesuvianite	Umpleby and Jones (1923)
Garnet	Ransome (1908)	Zoisite	Ransome and Calkins (1908)

Minerals of the hydrothermal veins			
Albite	Shenon (1938)	Kaolinite	McLellan(1947)
Ankerite	Shannon (1926)	Magnetite	Ransome and Calkins (1908)
Anthophyllite	Ransome and Calkins (1908)	Marcasite	Shannon (1926)
Arsenopyrite	Shannon (1926)	Margarodite	Shannon (1926)
Barite	Lindgren (1903)	Polybasite (?)	Shannon (1926)
Boulangerite	Shannon (1920) (2)	Proustite	Ransome and Calkins (1908)
Bournonite	Kaser (1934)	Pyrargyrite	Shannon (1926)
Calcite	Ransome and Calkins (1908)	Pyrite	Finlay (1903)
Chalcopyrite	Ransome (1906)	Pyrrhotite	Ransome (1905)
Chalcostibite	Ransome and Calkins (1908)	Quartz	Clayton (1888)
Chlorite	Ransome and Calkins (1908)	Scheelite	Blake (1889)
Clausthalite	Shannon (1926)	Siderite	Clark (1900)
Dolomite	Ransome and Calkins (1908)	Sphalerite	Clark (1900)
Galena	Clayton (1888)	Stibnite	Ransome and Calkins (1908)
Gersdorffite	Willard (1941)	Sylvanite	Shannon (1926)
Gold	Clayton (1888)	Tetrahedrite	Clark (1900)
Hematite	Shannon (1926)	Tremolite	Shannon (1926)
Jamesonite	Shannon (1926)	Uraninite	Thurlow and Wright (1950)

Minerals due to oxidation and secondary enrichment			
Anglesite	Shannon (1919) (2)	Leadhillite	Shannon (1919) (1)
Argentite	Shannon (1926)	Limonite	Wheeler (1889)
Azurite	Ransome (1908)	Linarite	Shannon (1919) (1)
Bindheimite	Shannon (1913)	Massicot	Jones (1919)
Bornite	Ransome (1908)	Malachite	Ransome (1908)
Caledonite	Shannon (1926)	Melanochalcite	Shannon (1926)
Cerussite	Clark (1900)	Minium	Shannon (1926)
Cervantite	Shannon (1918)	Plattnerite	Wheeler (1889)
Chalcocite	Ransome (1908)	Pellaneslane	Livingston (1919)
Chlorapal (?)	Shannon (1926)	Pyrolusite	Shannon (1926)
Chrysocolla	Shannon (1926)	Pyromorphite	Yeates and Ayers (1892)
Copper	Shannon (1926)	Silver	Clark (1900)
Covellite	Ransome and Calkins (1908)	Stibiconite	Shannon (1926)
Cuprite	Ransome (1908)	Stolzite	Shannon (1926)
Erythrite	Shenon and McConnel (1939)	Stremeyerite	Shannon (1926)
Goethite	Shannon (1926)	Sulphur	Shannon (1926)
Kermesite	Shannon (1918)	Trichalsite	Shannon (1926)
Lead	Shannon (1926)	Valentinite	Shannon (1918)

MINERALS OF THE COEUR D'ALENE DISTRICT.

In Table 1, an attempt has been made to list the known minerals occurring in place in the Coeur d'Alene district, showing what appears to be the earliest recorded reference for each in scientific literature. Several minerals described in categories contrary to interpretation in this study are omitted under those categories, but all minerals reported are listed unless their occurrence is logically refuted by later workers. Where a source is not given, the mineral has not been previously identified in that type of deposit.

The monzonitic-intrusive and associated contact-metamorphic minerals are not found in the Silver Belt. Most of the other minerals probably occur in the Silver Belt in at least minor amounts although many have not been specifically reported. On the other hand, a few, such as gersdorffite and proustite, which are reported from the Silver Belt but not elsewhere in the district, could probably be found outside the Silver Belt in minor amounts. The spatial distribution and genesis of each mineral known to occur in place in the Silver Belt are considered in this survey with the exception of those of the shallow oxidized zones.

MINERAL CONSTITUENTS OF THE BELTIAN SEDIMENTS.

General Discussion.

In the numerous (70 or more) geologic publications on the Coeur d'Alene district as a whole, some confusion has arisen in the segregation of the Beltian rock minerals from minerals of other categories. Such apparent discrepancies exist as the designation of sericite as a mineral of the extensive Beltian rocks by Lindgren (15), as a contact-metamorphic (exomorphic) mineral by Umpleby and Jones (31), and as a hydrothermal-vein-stage mineral by Rasor (22).

Lindgren (15) referred to most of the main minerals of the Beltian sediments. He described the thick series as consisting of banded quartzitic slates and heavy bedded quartzite, the latter consisting of rounded or subangular quartz grains with sericite in the cementing material. He also reported some clastic feldspar, tourmaline, and calcite. Ransome and Calkins (21) made a more detailed study and listed a number of other accessory minerals, although they attempted little evaluation of mineral distribution.

In the study of hundreds of thin sections of the Beltian sediments, the writer has attempted to define those minerals which are regional constituents and those due to localized alterations. Table 2 lists the minerals of the main Beltian lithologic types found in the Silver Belt. The lithologic data given are for rocks considered as unaffected by hydrothermal vein solutions or late oxidation. The minerals are essentially those recognized by Ransome and Calkins; siderite has been subtracted and the feldspars are specified.

Generally, all the Beltian rocks of the Coeur d'Alene district are of the three lithologies listed, together with gradational types. Commonly, where rocks have been subjected to hydrothermal bleaching alteration, contacts between the main sedimentary divisions can only be mapped within hundreds of feet due to the general lithologic similarity throughout the section. How-

ever, rocks approaching carbonatites are virtually limited to the Wallace formation whereas the Revett formation is mostly thick-bedded quartzite. The most common lithologic types of the Wallace are those approaching argillite and carbonatite, while those of the St. Regis are commonly quartzite and argillite (interbedded). The lithologic types defined may be considered as end points, whereas the most common rocks are gradational types

TABLE 2.

MINERAL CONTENT OF LITHOLOGIC TYPES OF BELTIAN SEDIMENTS UNALTERED BY HYDROTHERMAL VEIN SOLUTIONS.

Mineral	Genetic type*	Grain size** (microns)	Approximate volume percent		
			Quartzite	Argillite	Carbonatite
Quartz	SD	2.0–6	92	15–20	20
Sericite	D	2.0–105	3	75	5
Carbonates	S	2.0–150	N	N	70
Leucoxene	D	3.0–100	0.6	2	0.6
Tourmaline	D	2.0–200	R	0.4	R
K-feldspar	S	50.0–500	0–2	N	N
Albite	SD	50.0–100	0–0.5	N	N
Muscovite	S	50.0–200	1	R	R
Chlorite	D	2.0–500	N	R	R
Zircon	S	10.0–50	0.2	R	R
Hematite	D	0.8–40	R	R–8	R
Magnetite	SD	0.5–100	R	R–1	R
Pyrite	D	40.0–250	N	N	N
C-matter	S	0.8–20	R	0–3	0–2
Rutile	SD	2.0–10	N	R	R
Biotite	SD	15.0–50	0.5	N	N
Sphene	S	10.0–100	N	N	N
Pore space			0.6	N–R	—

* Genetic type: Sedimentary (S); Diagenetic or early metamorphic (D).
** Grain size is taken as longest dimension.
R = rare (0.01–0.10%).
N = negligible (0–0.01%).
C—matter = carbonaceous matter.
Carbonates include calcite, dolomite, and ankerite and *K-feldspar* includes orthoclase and microcline.

approaching "quartzite" and "argillite," and the use of such terms herein implies that the rock described approaches an end point. The terms carbonatite or limestone and dolomite are given as applicable to some Wallace beds. Terms such as quartzite, sericitic quartzite, calcareous quartzite, etc., which have been applied to various Beltian beds, are believed to be well chosen. Hobbs et al. (10) point out that, in a few localities, Wallace rocks could be called limestone. The term "argillite" is misleading but it is retained because of its long usage in the district. However, as used here it is considered synonymous with the more accurate terms, sericite schist and phyllite.

Certain structures of the Beltian rocks are of interest. Primary structures such as ripple marks, mud cracks, argillite chips in quartzite, and intertonguing of lithologies are common. Diagenetic features such as mottled and curved bedding are the rule, and concretions are found. Secondary

structures such as boudinage, isolated fragments of more competent beds, and filled tension fractures in competent beds are common. Either axial plane or shear cleavage is found everywhere except in the competent beds, and schistosity is almost ubiquitous.

The genetic classification of these minerals as given in Table 2 would probably date their formation as Precambrian. Their time relationship to the Paleocene (30) ore deposition would not be favorable in establishing them as indicators, according to the postulates listed above.

An indicative spatial distribution of these minerals relative to oreshoots resulting from mere coincidence seems unlikely, the most tenable explanation being the amenability of concentrations of the minerals in forming favorable deposition horizons for ore.

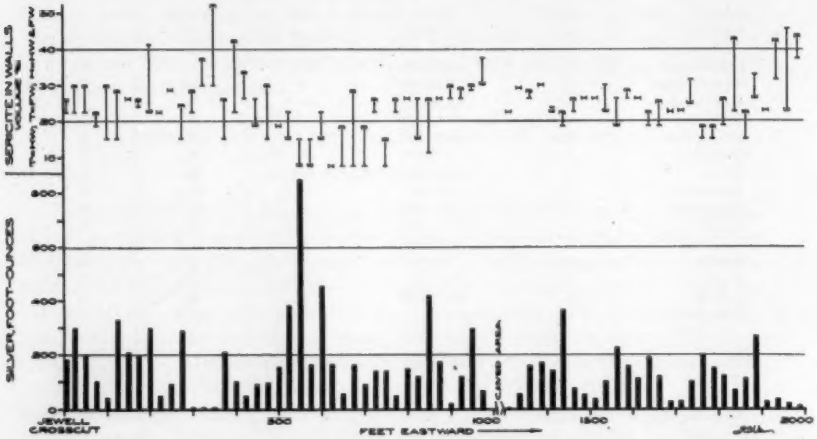

FIG. 4. Sunshine vein, 3,100 level; showing foot-ounce values of the vein and the sericite content of the walls. Observations are recorded for ten-foot sections on 25-foot centers along the strike. Foot-ounces are the product of the sampled width and the assay-ounce value of the vein. A correlation of high vein values and walls of low sericite content is evidenced. (Vein values were calculated from engineering records of the Sunshine Mining Co.) (Refer to Fig. 13 and Table 3.)

Indicators Among Beltian Minerals.

Major Minerals.—Observations in this study agree with the generalization of Ransome and Calkins (21) that sericitic quartzites are most favorable to the formation of large ore bodies. The three major constituents of the Beltian sediments in order of abundance are quartz, sericite, and carbonate. Because of the ubiquity and abundance of quartz, volume-percent estimates have not been made directly, but the residual volume after measurement of the other minerals has been assigned to quartz.

Rough estimates of the sericite content of walls of stopes and barren vein sections indicated that more than 30 to 40 percent (by volume) was rarely found in the walls of oreshoots. This estimate was then tested by systematic sampling along the strike of the Sunshine "A" Hanging Wall and the Sunshine "B" veins on the 3,100 level of the Sunshine mine (Figs. 4, 13 and Table 3). The sampling for sericite was done by making estimates for both walls of each 10-foot section on the basis of percent of each lithologic type and the sericite percent in the types. The sericite content for each wall was then calculated from the lithologic types. Before this sampling was undertaken, rock specimens were calibrated against thin sections. Also, thin-section checks were made at points along the line of sampling and a few thin-section estimates were verified with chemical analyses. From the latter, an adjustment factor was applied to the sericite volume-percent estimates.

Considering the results of the correlation shown, a sericite content of less than 35 percent in a group of beds is considered as favorable to the formation of ore, and, therefore, sericite is called a negative indicator. Generally, a

TABLE 3.

SHOWING CORRELATION BETWEEN WALLS OF LOW SERICITE CONTENT AND HIGH VEIN VALUES ALONG THE SUNSHINE "A" HANGING WALL AND THE SUNSHINE "B" VEINS. IN EACH CASE THE WALL RICHEST IN SERICITE IS ASSUMED TO BE THE CONTROLLING FACTOR (AN INTERPRETATION OF FIGURE 4).

Number of observations	Sericite content range	Vein values, foot-ounces	
		Range	Average
4	7.5–15	140–850	329
18	16–25	3–455	157
37	26–35	4–420	149
6	36–44	3–300	95
3	45–52.5	2–19	10

group of beds is a better ore horizon, the lower the sericite content. This does not preclude the existence of other factors which render beds favorable. For instance, a favorable sedimentary structure, according to Robinson (oral communication), appears to be beds of sericitic quartzite of roughly a 1-foot thickness alternating with 1 to 4-inch beds of argillite. Because rather abrupt facies changes are common, the reliance on sericite as an indicator is not always feasible.

At all points where carbonate-rich walls were observed, no ore was found, although strong mineralization was observed at some points. It is estimated that an excess of 30 percent by volume of calcite, dolomite, or ankerite in a bed, or especially a group of beds, in the Silver Belt indicates that nearby ore is unlikely. Expressed positively, rocks low in such carbonates are more favorable host rocks than those with a content in excess of 30 percent. Since this may provide a negative clue to the location of ore, these carbonates are considered as negative indicators.

A high quartz content appears to make a bed amenable to ore deposition. The most favorable wall rock lithology, defined in terms of mineral content, seems to be about 86 percent quartz, 7 percent sericite, 3 percent carbonate, and 2 percent accessory minerals (all by volume). The apparent tendency of sericite- and carbonate-rich rocks to preclude the deposition of ore is best explained by the physical nature of the minerals, which causes the rocks to behave more plastically under stress, thus forming fewer capillary and supercapillary openings.

Accessory Minerals.—Table 2 indicates the distribution of accessory minerals; however, the distribution of chlorite and tourmaline could not be clearly presented in the tabulation.

Ransome and Calkins (21) indicated that the green St. Regis beds near the Wallace contact contained chlorite, and Wagner (33) observed that chlorite was the coloring matter of green St. Regis beds south of the Coeur d'Alene district. Eleven specimens of green St. Regis rock studied by the writer were found to have a chlorite pigment varying up to 2.5 percent of the rock. Although occasional tension veinlets are found with crystals as large as 1 mm, most of the flakes are less than 0.1 mm in diameter. The optical properties of this dark-green chlorite are given in Table 7. Throughout the Beltian section much of the minor, scattered detrital biotite has been altered to chlorite, probably either diagenetically or before deposition.

Ransome and Calkins (21) reported tourmaline throughout the section, and indicated that it was more abundant in the argillites. Its euhedral and generally randomly oriented crystals are ubiquitous in occurrence but have been found to be abundant generally only in argillites (Fig. 11). In the central Silver Belt, in an area reaching from the Coeur d'Alene mine through the Sunshine, beds of relatively abundant tourmaline (volume percent in excess of 1) are common in the horizon near the St. Regis-Wallace contact (Fig. 6). One bed over five feet thick having a tourmaline content of over 25 percent was noted near the Silver Summit shaft on the lower tunnel level. Elsewhere in the district, this zone of relatively abundant tourmaline was not found at several sampling points.

No ore was found on structures along the tourmaline-rich horizon. This stratigraphic horizon is about equivalent to the horizon of relatively abundant chlorite on and near the St. Regis-Wallace contact. It was sampled at intervals from the Sunshine mine eastward into Montana. The chlorite zone was most continuous, although at some points neither chlorite nor abundant tourmaline was found. Very roughly, the area where relatively abundant tourmaline exists overlies many of the known oreshoots of the Silver Belt. However, no detailed spatial or genetic relationship seems to exist between the tourmaline beds and ore-bearing structures. The observations are not considered conclusive, and questions may be raised concerning the possible significance of tourmaline distribution. Its widespread distribution in minor amounts in all Beltian formations, both in the Coeur d'Alene district and at points as far as 20 miles from the district, is established. It is most likely of diagenetic origin. The questions are raised only relative to its concentrations in excess of 1 percent of the rocks.

THE BASIC DIKE MINERALS.

The monzonitic intrusives of the district have been described by Ransome and Calkins (21) who found them to vary in composition from syenite to diorite. Ransome and Calkins also described diabase and lamprophyre dikes, the minerals and textures of which are given in detail by Jones (11), Shannon (25e), and Shenon (26a) (see Table 1).

In the area of the Silver Belt mapped by Shenon and McConnel (27), the only known igneous rocks are diabase and lamprophyre dikes of small areal extent. In the critical part of the Silver Belt, between the Osburn and Big Creek faults, the only igneous rock occurrence shown is a markedly continuous diabase dike that runs the full length of the Silver Belt and parallels some of the major veins in strike (Fig. 3). Hershey (9d) claims that the diabase dikes are younger than the veins and have no genetic connection with ore (9a). A number of district geologists consider the diabase dikes to be late-pre-mineral. Their alteration may possibly coincide with the ore-depositing solutions. Certainly, in detail, there is no significant or consistent spatial relationship between the dikes and ore, although Shannon (25e) claims a close district-wide association with the veins.

Alteration products of basic dikes found elsewhere in the district were noted in the Silver Belt. Thin sections show large areas of almost pure pennine with scattered calcite. Also areas of almost pure chlorite of higher birefringence are found. Other alteration minerals noted were leucoxene, quartz, epidote, and sericite. Walls are chloritized up to two feet and chlorite is found in fractures up to 15 feet from the dikes.

THE HYDROTHERMAL VEIN MINERALS.

Paragenetic Features.

The hydrothermal history of the Coeur d'Alene district may be considered, from oldest to youngest, in three stages: (1) bleaching alteration stage, (2) carbonate-quartz stage, and (3) sulfide stage. Structural relations and spatial evidence support the belief that time intervals, when solutions were inactive, separate these stages—intervals of much greater duration than any within the stages. The areas of deposition of the stages became progressively less extensive with time. Although exceptions are common, the solutions of each stage generally followed the same openings. This conclusion is supported by evidence from sources in the literature as well as by the current study, although the division given herein differs both in mineral grouping and implications from those previously recorded.

The most complete paragenetic descriptions appear to be those on the Sunshine mine by Rasor (22) and the Polaris mine by Willard (36). Descriptions are given by a number of others, but the variable nature of the ores of the district has prevented any single study from covering all the hydrothermal minerals. Figure 5 shows an attempt to integrate the time relationships of those minerals of the district for which a sequence position has been given. Although the evidence seems in places conflicting, a general

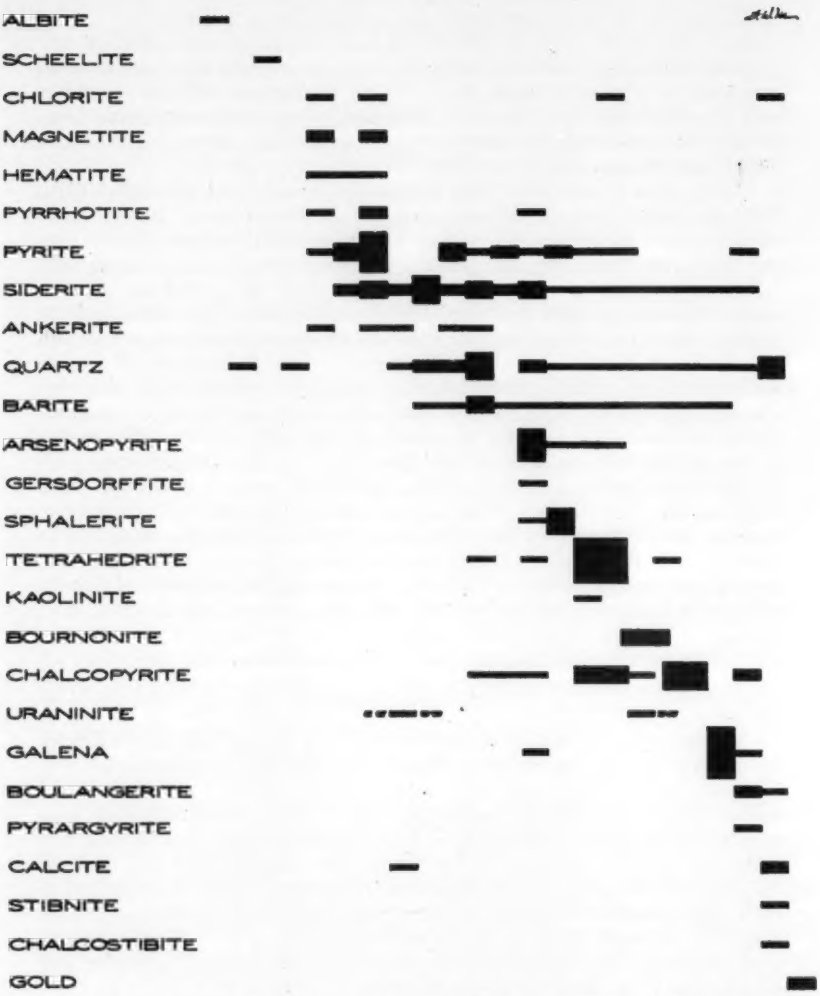

FIG. 5. Paragenetic diagram of some hydrothermal vein minerals, Coeur d'Alene district. This is an average of sequence descriptions in the literature, including observations of this project. Because no author has given a complete sequence and because some descriptions are vague, this is subject to considerable interpretation. Also, minerals not considered as hydrothermal by the writer are omitted. The thickness of the horizontal bars represents the number of papers (from 1 to 9) that described that sequence position for each mineral. After Ransome and Calkins (21), Hershey (9b), Ray (23), Umpleby and Jones (31), Waldschmidt (32), Shannon (25h), Rasor (22), Whiting (35), Anderson, R. J. (2), Willard (36), Shenon (26b), Sorenson (28) (average), Thurlow and Wright (29), Robinson (24).

consistency is indicated by the weight of the horizontal bars. To the compilation of the work of others the following sequence has been added: chlorite-magnetite-pyrite-hematite, siderite, ankerite, quartz, arsenopyrite, sphalerite, tetrahedrite-chalcopyrite-kaolinite, tetrahedrite-chalcopyrite-chlorite, and galena.

It is believed that the repeated periods of deposition of most of the minerals shown in Figure 5 is largely only apparent, i.e., actually being reworking of earlier minerals during the deposition of later ones. Also, some workers have pointed to the possibility that the gold-tungsten veins represent an entirely different age of mineralization (26a).

Bleaching Alteration Stage.

Bleaching Phase.—Rasor (22) first called attention to the hydrothermal bleaching of rocks in the Coeur d'Alene district. He noted that, in the Silver Belt, the extent to which the hydrothermal solutions had penetrated the vein walls was shown by the reduction of colored rocks to pale colors, e.g., the purple St. Regis being altered to pale green. He called this alteration sericitization, and stated that it had softened the rocks, thereby preparing them for later sulfide mineralization. Later, Shenon and McConnel (27), McConnel (17), Willard (36), and Sorenson (28a,b) described strong sericitization as the most important phenomenon of the bleaching process. These writers did not mention any relation between this sericite and that described as a constituent of the Beltian rocks by Lindgren (15). Wagner (33), working south of the Coeur d'Alene district, divided the sericitization into two stages, the earlier being regional and the later being due to hydrothermal solutions.

On the other hand, Shannon (25h) said that the sericite of the district is regional; its formation antedates the deposition of the ores and is in no way connected with them. Gale (7) thought that bleaching might be due to the same process which caused silicification and pyritization of the rocks, and omitted to state that it was sericitization. The hydrothermal sericitization idea, defined by Rasor and amplified by others, was generally accepted in the district until McLellan (18) stated that conversion of iron and other minor colored compounds to ferrous carbonate was by far the most important process causing bleached areas. His report cast doubt on hydrothermal sericitization and provoked discussion in the district as did statements by Mitcham (19) who pointed out that some argillite beds are almost pure sericite, and expressed doubt that a variation in sericite content was due to hydrothermal alteration. Hobbs et al. (10) maintained the earlier view but conceded that many of the argillites contained all the material necessary for the sericite developed in them, as did Sorenson (28c) who conceded that no positive evidence has been developed to support the theory that abundant potash had been added during the bleaching of the rocks.

The problem has some parallel to that faced by Graton and McKinstry (8) in the Porcupine district who concluded that it was difficult if not im-

possible to draw a distinction between "hydrothermal" and "regional" rock alteration in that area.

Ten thin sections were studied on bleached-unbleached contacts in the Wallace, St. Regis, and Prichard formations—mostly from the Silver Belt. Also, 20 samples of several lithologic types from bleached and unbleached

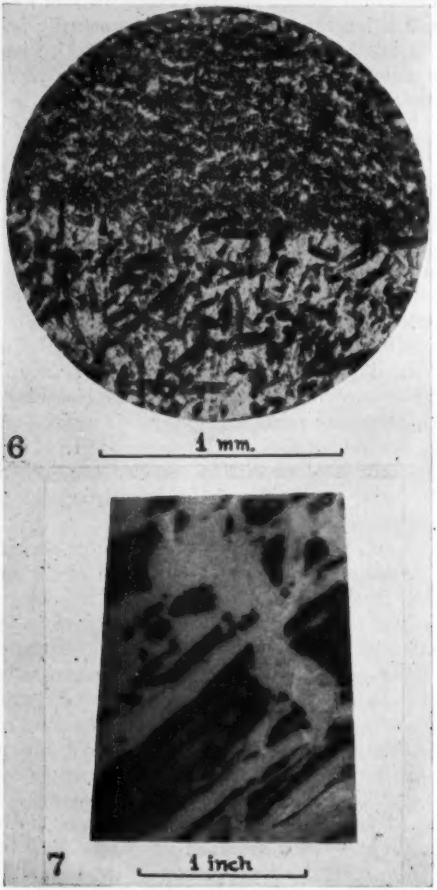

FIG. 6. Bedding contact between a bleached dolomite-rich bed (upper) and a dark green tourmaline-rich bed (lower). Sample is from a point near the Wallace-St. Regis contact.

FIG. 7. Wallace specimen showing bedding distorted during folding. Dark beds are mostly sericite, and the pigment is disseminated pyrite pyrito-hedrons. Bleached beds are more quartzitic.

rocks were compared by thin-section studies and in several samples by X-ray powder studies and chemical analyses (Table 4). Added to this were notations on hundreds of wall rock samples. Figures 6, 7, 10, 11, and 14 show the results of some of these observations.

It is concluded that the bleaching is the earliest hydrothermal stage as found by Rasor (22). Solutions penetrated the walls of early openings, generally destroying the pigment minerals of the rocks. The destroyed pigment minerals of the St. Regis are hematite and minor magnetite, and those of the Prichard and Wallace are carbonaceous matter and minor magnetite. Some Revett beds contain minor carbonaceous matter but generally lack pigment. The Burke and Striped peaks were not studied.

This process reduced colored rocks to pale tints, generally. However, tourmaline is resistant to the process and where beds contain concentrations in excess of about 0.7 percent by volume, the rock appears unbleached, showing a greenish-gray to dark greenish-gray color depending on the percent

TABLE 4.

CHEMICAL ANALYSES OF FOUR SILVER BELT ARGILLITES OF SIMILAR TEXTURE.

	Unbleached argillites		Bleached argillites	
	Wallace	St. Regis	Wallace	St. Regis
K_2O	6.27	7.28	5.14	7.34
Na_2O	1.16	0.30	0.29	0.35
MgO	3.10	0.57	0.55	0.31
Fe_2O_3	1.06	7.09	0.89	0.79
FeO	2.65	0.68	1.00	0.49
C*	0.83	—	—	—

Ratio of FeO to Fe_2O_3 is not definite in the unbleached Wallace due to presence of organic matter.

* Organic carbon.

(Fig. 6). Chlorite in the sediments is somewhat resistant to the bleaching process and is often only destroyed in part, the rocks retaining an apple-green color.

The carbonaceous matter apparently has been removed altogether. The color is destroyed in rocks where this is the primary pigment by heating them in air to 450° C.

The iron of the destroyed iron pigment minerals is probably converted to pyrite which is found disseminated everywhere in bleached rocks, but pyrite is generally quite scattered in rocks other than St. Regis. If converted approximately in place, very fine disseminations are found. Considerable migration has taken place, and some of the abundant iron of the St. Regis may have been moved into the Wallace as suggested by Sorenson (28c). This pyrite forms euhedral crystals with pyritohedral and cubic forms varying in size from .002 mm to over 18 mm. Concentrations of fine disseminations impart a gray, unbleached appearance to the rock (Figs. 7 and 11). This pigmentation depends both on the fineness and the relative per-

centage of the pyrite. Roughly, pyrite in excess of 0.8 percent by volume will cause the rock to appear unbleached if the crystal size is below .01 mm.

Shenon and McConnel (27) mapped bleached zones in the Silver Belt, showing their relation to structure (Fig. 2). Sorenson (28) has stressed the fact that oreshoots are most likely to be found in strongly bleached rocks. If strong bleaching means strong sericitization, then areas of abundant sericite should be favorable to ore deposition. Actually, as shown above, almost the exact opposite is true in the Silver Belt. Sorenson's generalization of the relationship of oreshoots to bleached rocks appears valid. However, the sericitization is regional in Beltian rocks and it is not generally connected with the localized hydrothermal bleaching stage. The only sericitization involved in the hydrothermal vein history is the alteration of the chlorite pigment in some beds and the negligible chlorite in scattered detrital biotite—this during the bleaching stage. Some rocks, which have undergone the bleaching process but which are yet dark in color due to excessive pyrite or tourmaline, have been mapped previously as unbleached.

In summary, the term "bleaching" best describes this hydrothermal stage, since in the process, pigment minerals are removed or converted to other minerals. Since iron oxides are converted to pyrite, pyritization is the most outstanding process of the stage. Most bleached rocks show no increase in sericite relative to unbleached rocks, and where an increase is indicated from the conversion of minor chlorite, it is negligible relative to the regional sericite content of the Beltian rocks. Likewise, no evidence was observed to connect the bleaching alteration with the relatively minor silicification at some points along carbonate-quartz veins. The bleaching alteration is generally localized in strongly folded and faulted areas.

The most likely explanation to indicate why strongly bleached zones broadly outline the ore-bearing areas of the Silver Belt is that they reflect early openings available to the bleaching solutions, and thus define these as opposed to later openings—as late as post-ore. The older structures may thus be subjected to all later periods of movement and be more open than younger structures at the time of ore deposition. Percent porosity determinations gave 1.89 for a bleached argillite and 0.73 for a bleached quartzite. A larger number of determinations would have to be made to draw any conclusion by comparing these figures with those of Table 2.

As to the distribution of pyrite, it was generally found to be richer along the walls of most veins than at distances away from the veins (Figs. 11 and 14), but no consistent pattern relative to oreshoots has been established.

Chlorite Phase.—Zones of chloritized St. Regis rocks are exposed at the Atlas mine east of the Silver Belt and south of the Osburn fault. These zones traverse bedding and are roughly parallel to faults. This occurrence of chlorite was described by Sorenson (28a,b) who considered that chlorite, accompanied by magnetite and specularite, constituted the earliest manifestation of hydrothermal-vein mineralization in the district.

McLellan (18) attributed the chlorite at the Atlas mine to the reaction of siliceous solutions on siderite and sericite. He concluded that the mineral

was principally a silicate of aluminum and iron with only minor magnesium content. This chlorite differs from that which is the pigment of some beds (Table 7).

Hobbs et al. (10) described a series of parallel zones of chloritic alteration east of the Silver Belt, confirming Sorenson's opinion that the chlorite was very early and suggesting that the mineral was replaced by sericite.

It is possible that the chlorite-pyrite deposits on the Phil Sheridan claim near Kellogg, which were described by Hershey (9a), are also of this genetic type.

Samples from the Atlas mine studied by the writer indicate that the chlorite is a wall rock alteration mineral which in some areas has entirely replaced the sericitic cementing material between the quartz grains. It has also replaced carbonates in the wall rock. At the contact of the quartz-siderite-ankerite veins, some of the chlorite has recrystallized along with other wall rock minerals. In some areas the chlorite is associated with the rather abundant disseminated pyrite, characteristic of the bleaching alteration, while in other areas, it is associated with magnetite.

It is probable that this chloritization is closely related genetically to the bleaching alteration process in the St. Regis, since the chloritization seems to accompany the migration and conversion of iron of the abundant hematite in the fresh St. Regis rocks. The association of hematite with magnetite and chlorite as mentioned by Sorenson supports the conclusion that perhaps this chloritic alteration is a weak expression of the bleaching process. Since this early hydrothermal chloritization is a likely *phase* of the hydrothermal bleaching process, the association of chlorite and pyrite would be an intermediate stage between the weak chlorite-magnetite phase and the strong pyrite (bleached) phase. Thus, this chloritization and the bleaching are probably essentially contemporaneous.

In the Silver Belt, this phase is poorly represented. The rather rare hematite and magnetite in a few veinlets and that in the "Copper" vein of the Sunshine mine may represent this phase.

Carbonate-Quartz Stage.

General Description.—Carbonate veins are considerably more abundant in the Silver Belt than in most other parts of the district (4). The most consistent sequence of this stage is siderite, ankerite, and quartz plus minor barite, although exceptions probably exist, and the order is modified by some workers (Fig. 5). In the Silver Belt, most carbonate-quartz veins are found in rocks that have undergone bleaching-stage alteration.

Iron carbonate-bearing solutions were introduced both into openings along which earlier pyrite had been deposited by replacement and into later openings. These solutions replaced the country-rock along fractures and fracture zones, resulting in replacement veins comprised mostly of siderite and of country-rock remnants which are somewhat recrystallized. Minor fracture fillings can be found within these veins and for short distances into their walls. Fractures in early pyrite crystals filled with siderite are common. It seems likely that

disseminated siderite was formed in advance of the replacing front, forming zones penetrating into the walls of the veins from 0 to 80 feet (Fig. 14). With time, these solutions became richer in calcium and magnesium, and ankerite was deposited. In some samples the ankerite contains finely intergrown calcite, showing that the calcium ion was in excess in the depositing solutions at those points. Then the solutions became silica-rich and quartz was deposited.

Any time intervals, which may have elapsed between the phases of the carbonate-quartz stage, were minor. The phases probably graded directly into one another. Fractures in crushed minerals filled with minerals of the same and later phases, occasional crude schistosity parallel to planes of the veins, and the scarcity of perfect crystals all point to almost continuous movement on fracture zones during the carbonate-quartz stage.

The advance of the replacing front of carbonate is illustrated in Figure 9. Here the fine sericite-quartz cementing material of the quartzite is replaced first. Some recrystallization and accompanying limited migration of most wall rock minerals are noted. Resistant tourmaline is occasionally found in accumulations along siderite crystal interfaces, as if swept on an advancing crystal front as other wall rock minerals were dissolved. In one sample from the Yankee Girl vein, sericite recrystallized to 3-millimeter muscovite crystals was noted. Likewise, various stages of conversion of sericitic quartzite to vein quartz were observed. Carbonate samples without contamination of wall rock minerals in excess of 5 percent are quite difficult to find.

Vein structures noted may be described as anastomotic, hammock, composite, lenticular, and even ptygmatic. Widths of individual veins are generally quite variable and are usually less than two feet, rarely exceeding 3 feet. Composite veins sometimes exceed an aggregate of 10 feet in width. Crustification is generally lacking. A striking and common internal vein structure is the quartz ladder pattern on shear and transverse tension fractures where carbonate veins are generally massive.

In decreasing order of abundance, the principal minerals of this stage are siderite, quartz, ankerite, calcite, and barite.

Carbonates.—Numerous thermal analyses and 14 chemical analyses of Silver Belt vein carbonates reveal a substantial variation in the chemical composition of siderite and ankerite (Fig. 12, Table 5). The chemical analyses were made for reference standards to serve in the interpretation of the thermal curves and were made on samples selected as representative of the composition ranges of Silver Belt carbonates. Thermal analyses were made on a multiple differential thermal unit described by Kerr and Kulp (12) and Kulp and Kerr (14).

It is of interest to note that the iron and magnesium content of all Silver Belt siderite examined falls within the range of two samples analyzed by Shannon from other parts of the district. Although not shown in the table, Shannon (25h) listed analyses for four vein dolomite samples, i.e., minerals in which magnesium exceeds iron. No vein dolomite was found in the Silver Belt. The only hydrothermal-vein calcite found in the Silver Belt was in minor amounts and finely intergrown with ankerite and siderite, as in the

ankerite sample shown from the Silver Summit mine which is about 20 percent calcite.

Considerable effort was devoted to an attempt to establish a significant distribution pattern of siderite and ankerite of various compositions relative to oreshoots. No consistent pattern was found. Sorenson (28c) reports that generally light colored carbonates grade downward into siderite, which he

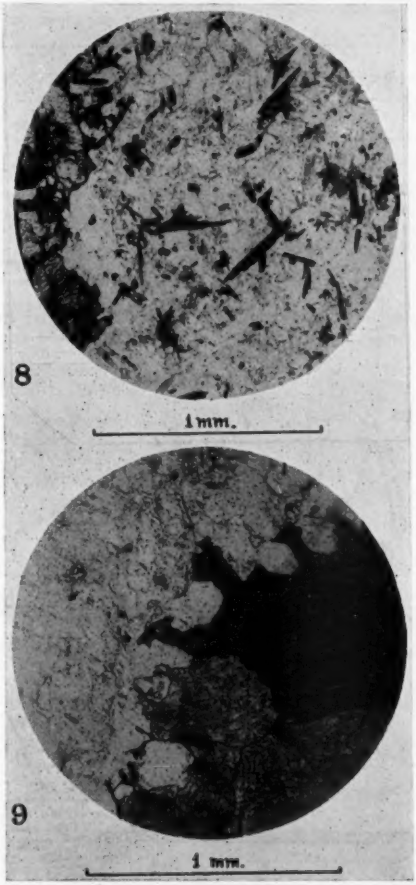

FIG. 8. Showing arsenopyrite replacement of the sericitic quartzite hanging wall of the Sunshine Footwall vein (siderite on left-hand side of photograph).

FIG. 9. Hanging wall contact of Yankee Girl vein showing siderite at the replacement front first attacking the sericite and fine-grained quartz, the cementing material of the quartzite (left).

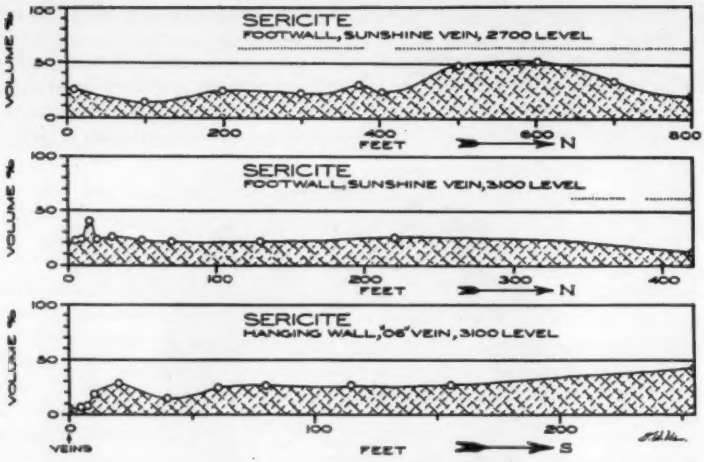

FIG. 10. (Upper.) Cross-sectional sampling for sericite in vein walls, Sunshine mine. All samples are in the St. Regis formation, and dotted lines represent unbleached zones.

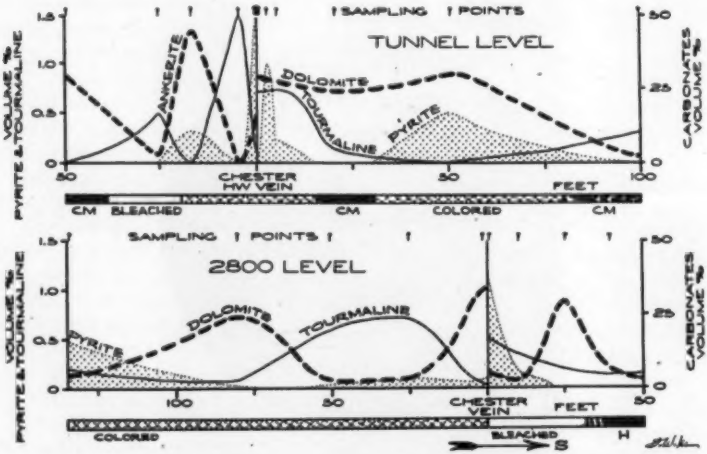

FIG. 11. (Lower.) Cross-sectional sampling in Chester vein walls, Silver Dollar mine. Bands below graphs show alteration zones. Black zones are unaltered where the main pigment is either carbonaceous matter (CM) or hematite (H), while in the "colored" zones these are absent and the pigment is pyrite and/or tourmaline.

says is the most favorable gangue mineral for ore. Statistically, this may be a valid generalization, but it should be noted that some of the deepest and richest oreshoots contain abundant ankerite. At nearly all sampling points, siderite was found in excess of ankerite. In two veins, however, ankerite was the only carbonate found; these were the Merger "D" and the Commodore-Truxton.

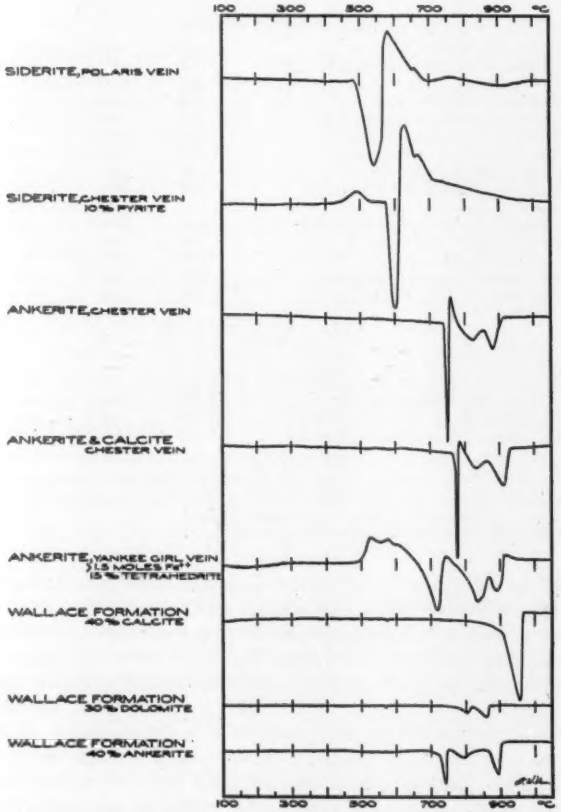

FIG. 12. Selected thermal curves of representative Silver Belt carbonates.

Quartz.—Broadly, two types of quartz belonging to this stage are found in the Silver Belt. One is recrystallized quartz of the country-rock from which the accompanying wall rock minerals have been largely dissolved. Commonly, gradations are found between it and virtually unaltered sericitic quartzite. This quartz seems to have migrated over distances measured in centimeters

TABLE 5.

CHEMICAL ANALYSES OF SIDERITE AND ANKERITE.

Samples	Moles			
	Fe^{++}	Mg^{++}	Mn^{++}	Ca^{++}
Siderites				
North vein, Coeur d'Alene mine	.888	.031	.081	Tr.
North Polaris vein, Sunshine mine*	.880	.033	.087	Tr.
Siderite vein, Coeur d'Alene mine	.885	.035	.073	.007
Sunshine vein, Sunshine mine	.868	.041	.089	Tr.
Silver Syndicate vein, Sunshine mine	.873	.048	.078	Tr.
Yankee Girl vein, Sunshine mine	.866	.052	.077	.006
Siderite vein, Coeur d'Alene mine	.852	.061	.083	.004
No. 3 vein, Silver Summit mine	.835	.063	.093	.008
Sunshine vein, Sunshine mine	.827	.077	.096	Tr.
Sunshine vein, Sunshine mine	.842	.082	.070	Tr.
Silver Summit vein, Silver Summit mine	.826	.084	.085	.005
Chester vein, Silver Dollar mine*	.822	.107	.068	.003
Rasor (1934), Sunshine mine	.859	.045	.087	.009
Shannon (1926), Coeur d'Alene district	.911	.031	.052	.006
Shannon (1926), Coeur d'Alene district	.785	.132	.074	.009
Ankerites				
Chester vein, Silver Dollar mine*	1.176	.662	.162	2.060
Chester vein, Silver Summit mine*	1.155	.596	.249	3.090
Shannon (1926), Coeur d'Alene district	1.274	.520	.206	1.990
Shannon (1926), Coeur d'Alene district	1.415	.463	.122	1.833

Moles are calculated assuming siderite as (Fe,Mg,Mn,Ca) CO_3 and ankerite as 2 $CaCO_3 \cdot$ (Fe,Mn) $CO_3 \cdot MgCO_3$. In ankerite, Fe + Mg + Mn is assumed as 2 moles and thus Ca should be 2 moles; the high calcium value is due to intergrown calcite.

* Thermal curves are shown for these in Figure 13.

to fill cleavage fractures in carbonates and also to become intimately intergrown with the carbonates. The second type, although probably from the same country-rock source, has migrated farther for unknown distances. The two types are not always distinguishable from each other. There is a tendency for the transported quartz to be milky, whereas the recrystallized quartz tends to be translucent to transparent. The milky quartz contains abundant liquid-gas inclusions (10^8 to 10^9 per cubic centimeter), the diameters of which vary from 0.5 to 1.4 microns. Nearly all quartz of this stage shows abundant evidence of heavy strain, e.g., much distorted crystals, a crude schistosity, complex twinning, and shear fractures filled with granulated quartz.

Solutions during the quartz phase of this stage possibly penetrated the walls of veins for distances up to 100 feet, but the only material added to the walls was a minor amount of silica resulting in silicification in scattered areas within a few feet of veins. However, evidence of limited recrystallization and short-distance migration of quartz and sericite was noted farther from veins. Striking pressure shadows of quartz around pyrite crystals were noted which are similar to those described by Knopf (13). However, no consistent sig-

nificant pattern of distribution of vein quartz relative to ore has been established.

Barite.—This is a rare mineral in the Silver Belt veins, but it is rather abundant to the east of the Silver Belt (10). Although it probably occurs in minor amounts in other areas of the Silver Belt, it was only noted in the No. 3 vein (Fig. 3) and closely associated structures.

Ore Minerals of the Sulfide Stage.

General Description.—Although exceptions may be found, the prevailing sequence of deposition of the late sulfides found in the Silver Belt seems to have been arsenopyrite-gersdorffite, sphalerite, tetrahedrite, bournonite, chalcopyrite-pyrite, galena, and boulangerite-pyrargyrite. The relative period of deposition of proustite is not known, but it is probably about contemporaneous with pyrargyrite. Other minerals, probably of this group and found elsewhere in the district, have not been found in the Silver Belt (Table 1). The closely spaced sequence of deposition should favor an attempt to utilize the late sulfides as indicators of silver ore, as postulated.

Gersdorffite, bournonite, boulangerite, proustite, and pyrargyrite are rare within oreshoots and very rare or absent outside oreshoots, and their distribution pattern appears to be sporadic.

Minor occurrences of uraninite possibly were deposited during this stage (29, 24). The writer has not surveyed its distribution because the occurrence is being carefully studied by others. It does not seem, however, that it is an indicator for silver ore.

Arsenopyrite.—Rasor (22) describes arsenopyrite as intimately fractured and replaced by tetrahedrite. Anderson (2) descirbes it as intimately associated with tetrahedrite. Outside the Silver Belt at the Stanley mine, Shannon (25b) found arsenopyrite as a common constituent of vein walls but not of the veins themselves. In the Silver Belt the mineral shows a marked preference for the sericitic quartzite of the vein walls rather than replacing vein quartz and carbonate. The normal occurrence of arsenopyrite is strikingly illustrated by Figure 8. Most of the arsenopyrite within the veins has replaced wall rock slivers. The mineral is in the walls of most of the highest grade oreshoots of the Silver Belt, namely, shoots of the Sunshine "A" (Hanging Wall and Footwall veins), Sunshine "B," "06," Chester, Yankee Girl, and No. 3 veins. Furthermore, all occurrences noted are on veins that are known to contain rich oreshoots except for those along the No. 2 vein of the Silver Summit mine and on veins in the footwall of the Sunshine vein on the 3,700 level. In both cases, the structures are closely related to ore-bearing structures and could be connected up or down dip. Also, in both cases, separate ore-bearing structures might be indicated.

These arsenopyrite zones are graphically shown in Figures 13 and 14. The zones are mostly narrow but extend into the walls for distances varying from a few millimeters to over 80 feet. They were found in the walls of ore-bearing veins opposite oreshoots, at distances as great as 300 feet up dip from ore (Fig. 16), and at distances as great as 500 feet strikewise from ore.

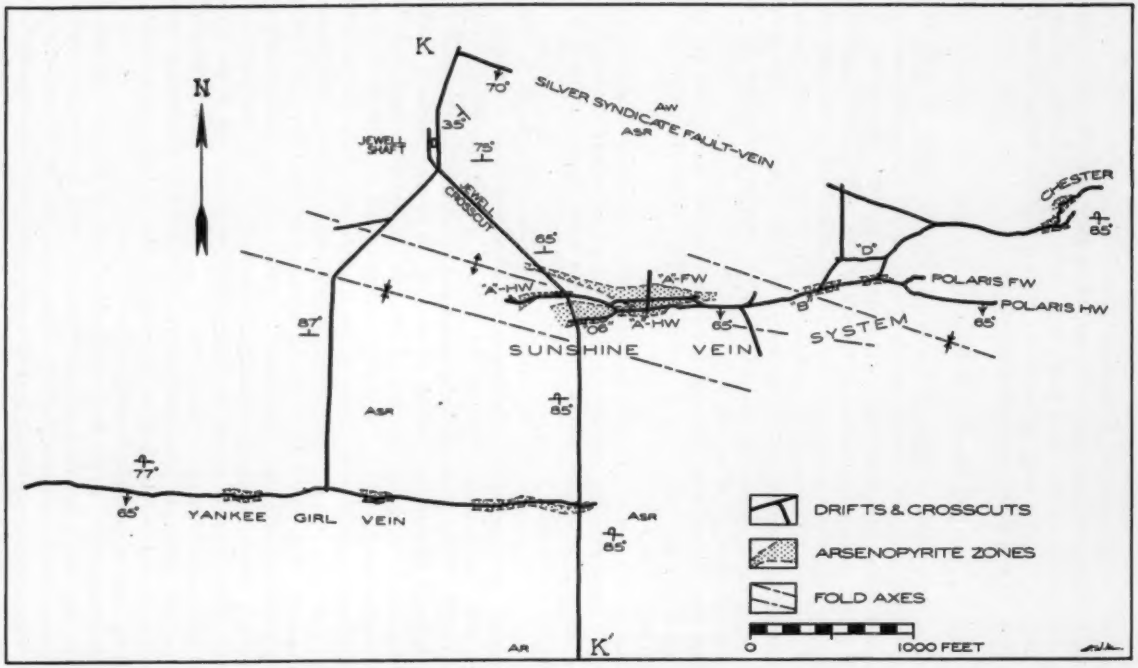

FIG. 13. Plan of 3,100 level, Sunshine mine; showing location of veins and arsenopyrite zones in their walls. Aw: Wallace fm.; Asr: St. Regis fm.; Ar: Revett fm.

The arsenopyrite zone exposed in the Jewell crosscut and 170 feet in the footwall of the "A" Hanging Wall vein (Figs. 13, 14) is in a fractured zone which is the probable extension of the "A" Footwall vein. This point is at least 500 feet from the nearest known ore in this vein.

Zones of arsenopyrite found in the Silver Belt are the following: on the 3,100 level plan; along the Yankee Girl vein on the 2,700 level; along veins on the 3,700 level at distances 130 and 200 feet in the footwall of the Sunshine "A" Hanging Wall vein; and along the Silver Summit veins at points from the 3,000 to the 3,400 level. Because of sampling limitations, even these probably do not represent all of the arsenopyrite zones that can be demon-

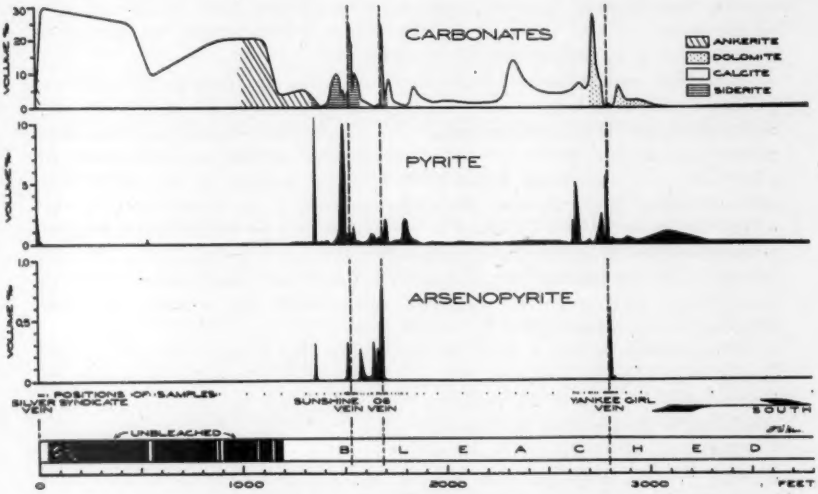

FIG. 14. Results of wall-rock sampling along section K–K: (see 3,100 level map of the Sunshine Mine).

strated in the Silver Belt. Zones such as those on the Sunshine 3,100 level are probably more continuous than shown.

The arsenopyrite in the walls occurs as disseminated, fine-grained, generally needle-like, euhedral crystals that replace quartzite and argillite, but show some preference for the cementing material of quartzite. The length of the crystals is mostly less than 0.10 mm but the range is from 0.01 to 1.0 mm. The volume percent of the arsenopyrite in the walls is usually less than 0.5 percent but varies from 0.005 to 10.0 percent, being generally higher in samples near the veins. Blebs of tetrahedrite are often seen replacing arsenopyrite crystals in veins.

These arsenopyrite zones may often be recognized in the field. If the arsenopyrite content is in excess of 0.1 percent by volume, a pale gray to dark

gray color is imparted to the bleached wall rock. This coloration is similar to that caused by disseminated pyrite, but the presence of arsenopyrite often can be detected by the odor of arsenic given off when the dark colored rock is struck a hard glancing blow with a pick. In more concentrated zones, some crystals are often commonly large enough to be identified megascopically. In some areas, mine oxidation has formed coatings of erythrite on arsenopyrite-bearing rocks. Metallic concentrates from these rocks yield cobalt, which is either in the arsenopyrite or perhaps in minute amounts of gersdorffite associated with the arsenopyrite; gersdorffite of the area is cobalt-bearing (36). Cobalt was not detected by ordinary qualitative tests on arsenopyrite from areas where erythrite coatings were absent. In areas where an erythrite coating was observed, however, arsenopyritite was the main metallic mineral in the rocks. Where the arsenopyrite content is low, it may be detected in thin sections or by testing panned concentrates.

The time association in depositional sequence of arsenopyrite with argentian tetrahedrite is favorable. The spatial pattern is quite significant since arsenopyrite seems to form envelopes—not simply around areas of tetrahedrite mineralization—but rather around concentrations of that mineralization, or silver ore. Its occurrence seems limited to this relation in the Silver Belt, and although it does not occur about all oreshoots, it was found about several of the richest oreshoots. Viewed in horizontal plan or vertical cross-section, these envelopes are narrow, averaging only a few feet; viewed from a direction normal to an ore-bearing vein, a halo of arsenopyrite occurs about oreshoots extending at least up to 300 feet above ore and 500 feet laterally from ore. Arsenopyrite is considered to be an indicator.

The question is raised as to the possibility that arsenic and cobalt form larger, trace-element envelopes about oreshoots. This might be worthy of investigation because of the tendency for arsenopyrite to penetrate the walls considerably farther than tetrahedrite.

Sphalerite.—Sphalerite, an important ore mineral elsewhere in the Coeur d'Alene district, is insignificant in most of the Silver Belt, the Galena mine being an exception. Concentrations of the mineral are either in oreshoots or in masses almost rich enough to be oreshoots. Because of its limited and sporadic occurrence, the spatial distribution of sphalerite has little indicative value in defining the position of silver-lead ore bodies.

Tetrahedrite.—Argentian tetrahedrite is the most important ore mineral in the Silver Belt. The composition varies considerably (Table 6). Records of the Sunshine Mining Company show a variation from .066 to .430 in Ag:Sb ratio in the Silver Belt. Annual averages of this ratio for the Sunshine vein system have varied from .122 to .358 for a ten-year period. The Sunshine concentrates have an average bismuth content of about 0.10 percent and an average arsenic content of about 2.0 percent. The bismuth is probably in the tetrahedrite, as well as part of the arsenic.

At all sampling points [3] along ore-bearing veins within 150 feet of oreshoots, tetrahedrite was observed. Beyond this, for any distance along a vein

[3] By "sampling point" is meant a 5-foot section of the vein.

it seems randomly distributed, present at some points and absent at others. This applies above, below, and laterally away from oreshoots within ore-bearing veins. Tetrahedrite is also found at points in apparently barren veins.

TABLE 6.

ANALYSES OF ARGENTIAN TETRAHEDRITE.

Source	Mine	Percent									
		Cu	Sb	S	Ag	Fe	As	Pb	Zn	Bi	Hg
Shannon (1920) (1)	Hypotheek	37.70	26.81	26.49	Tr.	5.13	Tr.	0	3.87	Tr.	—
Rasor (1934)	Sunshine	33.70	25.90	24.10	5.75	5.05	1.18	0.20	—	—	—
Ransome and Calkins (1908)	Polaris	Pres.*	Pres.	Pres.	Pres.		Pres.				Pres.
Willard (1941)	Polaris	—	—	—	—	—	0.76	—	—	—	None
Sunshine Min. Co.	Sunshine	26.2	26.1	—	11.21	—	—	—	—	—	—
Sunshine Min. Co.	Sunshine	10.7	6.0	—	0.67	—	0.85	(impure sample)			

* Present.

The generalization that the silver content of the tetrahedrite diminishes east and west of the Sunshine mine (*27*) prevails in part, but the silver-rich tetrahedrite of the Silver Summit mine (28b) constitutes a noteworthy exception.

With qualifications it appears that tetrahedrite occurs in halos of 150-foot radii in the plane of the veins around oreshoots. However, the fact that it may also be found 5,000 feet away would seriously detract from the value of any particular occurrence as an indicator of an oreshoot. Continuous showings of tetrahedrite 50 to 100 feet in strike length would appear significant. While the significance of tetrahedrite has not been completely evaluated, it would seem that concentrated statistical work on the problem might produce useful results.

Chalcopyrite and Pyrite.—Chalcopyrite is a minor mineral in the Silver Belt ore, but in scattered areas, it equals or even exceeds the tetrahedrite in quantity. Outside oreshoots, it is only rarely that it occurs in excess of tetrahedrite. Its distribution seems sporadic, and generally no significant pattern is indicated within or outside oreshoots. However, it is generally more abundant in oreshoots to the east of the Sunshine mine. Except for that in the veins of the Silver Summit mine, it is rare outside oreshoots.

In some specimens late pyrite can be differentiated from early pyrite of the bleaching stage. Attempts to correlate different crystal forms with the two types were not fruitful. Generally, the late pyrite is believed to be much less common than the early pyrite. In the distribution discussion of the pyrite above, the two types are not differentiated.

Galena.—It has long been recognized at the Sunshine mine that galena forms a capping on oreshoots. Durham (oral communication) has noted that in following an oreshoot upward, an increase in galena often signifies the

proximity of the upward termination of the shoot. This vertical zoning is markedly illustrated in the Sunshine vein system where the weight ratio of Pb:Ag was as high as 89:1 in the upper levels and as low as 0.5:1 in the lower levels (Fig. 15). It is also illustrated by the Chester vein oreshoots in the Sunshine mine. This capping is found in shoots with crests at or near the surface and in shoots with crests over 3,000 feet below the surface.

At some sampling points in oreshoots, galena cannot be found. Outside of oreshoots in veins, the distribution is sporadic and no pattern has been noted. In veins, it was absent at some points near oreshoots and present at one point 2,000 feet from an oreshoot. It is also found in veins considered as barren of oreshoots.

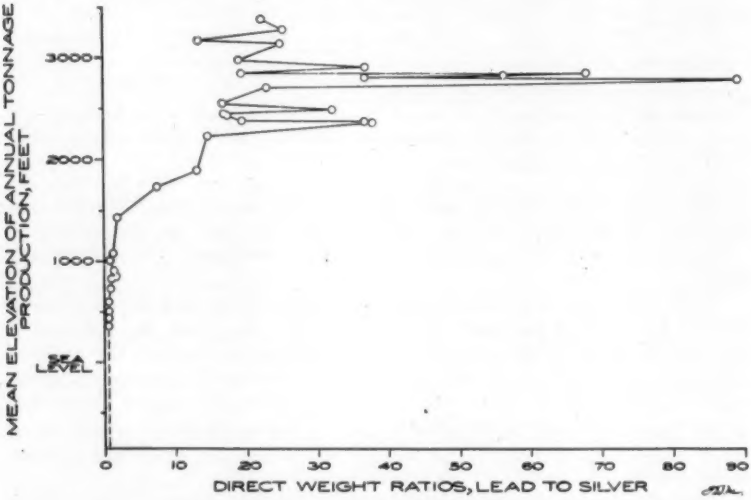

FIG. 15. Diagram showing evidence of a galena capping on the Sunshine vein system oreshoots.

Gold is about the latest mineral to form in the Coeur d'Alene district. The mineral association of the trace of gold in Silver Belt ores is not known. Since a decrease in gold with depth is indicated by concentrate assays from the Sunshine vein system, it may be in the galena.

Gangue Minerals of the Sulfide Stage.

General Description.—Except for some scattered late quartz, the gangue minerals of the sulfide stage in the Silver Belt seem to be chlorite and minor clay. Late calcite, as noted by Willard (36), was not observed.

Hershey (9a) mentioned an occurrence of chlorite in the Kellogg area, where the mineral is found in fractures. He described its distribution as

irregular and suggested that it might have a different genesis from that occurring in contact-metamorphic areas. Umpleby and Jones (31) mentioned that a little chlorite is developed on the parallel planes of the shear zone of the Morning lode. In the Pine Creek area, south of Kellogg, Shannon (25h) noted chlorite surrounding ankerite and replacing quartzite. Outside of the Silver Belt at the Frisco mine, chlorite was noted in the Frisco vein. It seems likely that the above occurrences are genetically similar to those described below.

Chlorite of the sulfide stage is mostly fine-grained (around 10 microns) and is generally a minor constituent in a mixture of fine-grained minerals. Material of this sort may vary considerably in composition. It changes from olive-green, showing virtually no pleochroism, to a type showing strong

TABLE 7.

OPTICAL PROPERTIES OF SOME CHLORITES IN AND NEAR THE COEUR D'ALENE DISTRICT.

Genetic type		Diagenetic	Contact-metamorphic	Early hydrothermal-vein	Late hydrothermal-vein	Late hydrothermal-vein
Location		St. Regis fm.	Avery district	Atlas mine	Silver Belt	Pine Creek
Optical group		Biaxial	Biaxial	Biaxial	Biaxial	Biaxial
Sign		+	+	—		—
2V		±5°	±0°	0–5°	±0°	±0°
Indices	α	1.602±.002	1.595±.003	1.649	1.602–1.658 (range for 48 samples; 20 were ±1.658)	About 1.640–1.645
	β	1.602±.002	1.595±.003	1.655		
	γ	1.607±.002		1.655		
Pleochroism	X	Bluish green	Weak	Pale yellowish-brown	Pale green to olive-green to pale yellow (some very weak)	Pale brownish green
	Y	Bluish green		Pale green		Bluish green
	Z	Reddish brown		Pale green		Bluish Green
Source		Present report	Shannon (1926)	McLellan (1947)	Present report	Shannon (1926)

pleochroism (Table 7). The mineral is iron-rich and has a weak birefringence. On a sample of possibly the same type of chlorite from the Pine Creek area, Shannon (25h) gives the following analysis:

SiO_2	21.56%	MgO	8.62%
Al_2O_3	20.44%	CaO	0.10%
FeO	39.40%	H_2O	9.88%

Spatial Distribution of Chlorite.—Late hydrothermal chlorite is an uncommon mineral in the Silver Belt. It occurs in few areas and even where found it is scarce. The five occurrences observed are described below.

1. On the 2,700 level of the Sunshine mine, chlorite occurs in the Yankee Girl vein and its immediate walls, at points above oreshoots (Fig. 16).
2. On the tunnel level, the 600 level, and 3,000 level of the Silver Summit mine, chlorite occurs above ore, as well as in and near ore on the 3,000 level and below (Fig. 3).

3. On the tunnel level at the Galena mine, chlorite occurs at points above oreshoots (Fig. 17).

4. On the 2,800 level of the Coeur d'Alene mine, chlorite occurs both in the American Silver veins and in broad zones in the walls. In the hanging wall of the "B" vein, occasionally it can be found on fractures and joints as far as 1,330 feet from the vein (Fig. 18).

5. On the 3,100 level of the Sunshine mine in the hanging wall of the Yankee Girl vein, chlorite occurs on fractures and joints in the Revett formation. These occurrences are found in zones lying within the following intervals measured from the Yankee Girl vein: 765 to 1,515 feet; 1,765 to beyond 2,270 feet.

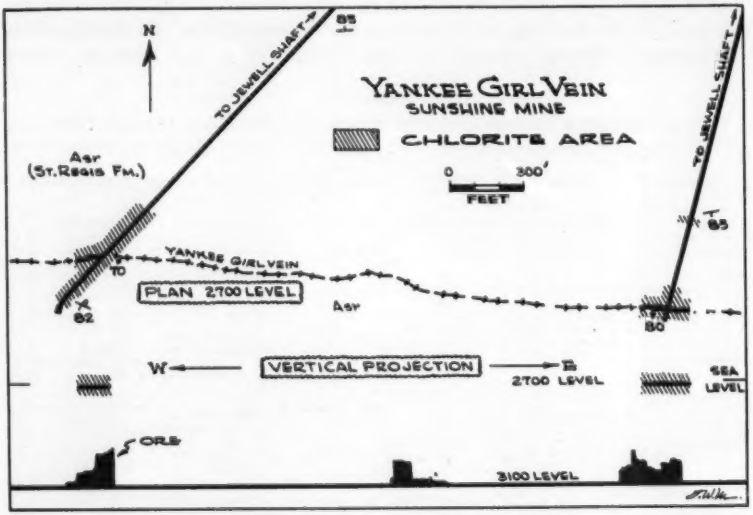

FIG. 16. Chlorite occurrences, Sunshine mine. Arsenopyrite also occurs in narrow zones along the vein on the 2,700 level.

The above areas of occurrence of late hydrothermal chlorite were the only ones noted in the Silver Belt. Robinson (oral communication) stated that he had seen some chlorite in the 3,100-level stopes of the Yankee Girl vein. Available openings limit the extent to which the strike length of a chloritic zone can be determined above an oreshoot or laterally on its flanks. On the 3,000 level of the Silver Summit mine, chlorite occurs 350 feet away from the ore in the No. 3 vein.

There are three types of relationships of this chlorite to structure. First, it occurs as scattered, greenish-gray, irregular patches (maximum dimension of 1 to 50 mm) on the numerous shear planes in the country-rock immediately on the vein walls and within the veins. These patches are separated by distances which vary from a few millimeters to several feet, and form thin films which usually show striations and sometimes slickensides due to post-late-

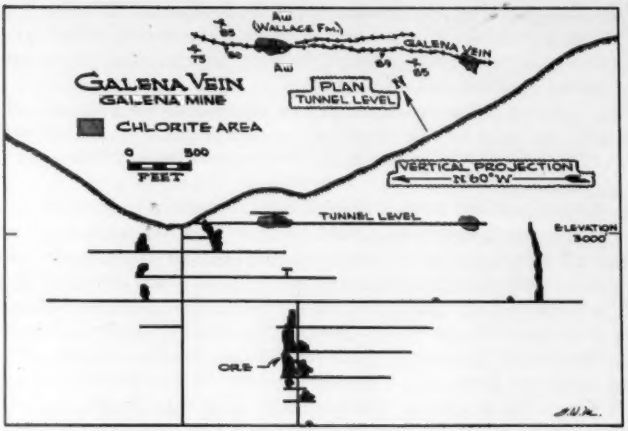

FIG. 17. (Upper.)

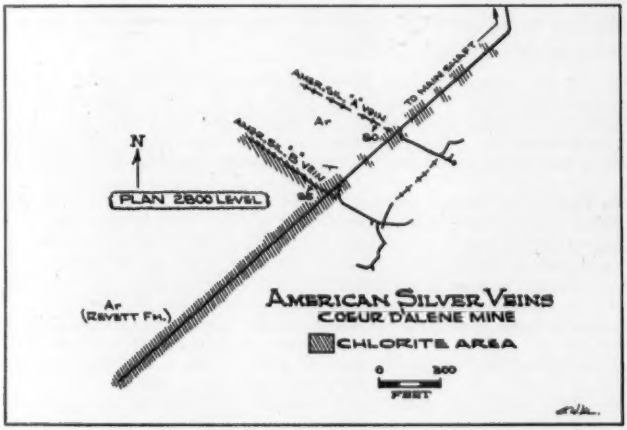

FIG. 18. (Lower.)

chlorite movement. Second, it occurs as the filling of late veinlets within the veins. The veinlets are generally a fraction of a millimeter in thickness and are olive- to dark-green. Third, the late hydrothermal chlorite occurs as continuous dark-green films on small fractures and joints about 0.1 mm in thickness. Such occurrences extend far into the hanging walls of the Yankee Girl and American Silver "B" veins in the Revett formation.

Time Relationships of Chlorite.—Late hydrothermal chlorite is accompanied in nearly all localities by one or more clay minerals which are about contemporaneous, but a little earlier. Some of this clay is kaolinite, but traces of unidentified clay minerals are also present.

In the scattered patches on shear planes, the chlorite and clay are intimately mixed with fine and broken fragments of the various wall rock minerals. This is true, also, to some extent in the veinlet chlorite and that occurring on joints and fractures.

The chlorite and clay replace sericite and the carbonates in some instances. Studies of samples from the No. 3 vein indicate that the chlorite and clay are later than all other gangue minerals, with the possible exception of some late drusy quartz. Veinlets of chlorite cut sphalerite in a sample from the Frisco vein at the Frisco mine. There is some suggestion that veinlets of chlorite and clay cut chalcopyrite in the Silver Summit No. 3 vein samples. Tetrahedrite occupies the central portions of some veinlets of chlorite. Bands of chlorite and clay surround chalcopyrite and tetrahedrite in a relationship suggesting reaction rims. Consequently, it seems likely that this chlorite and the clay associated with it are closely related in time with the deposition of chalcopyrite and tetrahedrite.

Chlorite, a Possible Indicator.—The *time* relationship of the chlorite seems significant. The spatial relationships, however, are not as well established. An evaluation of the favorable and unfavorable factors involved in the spatial distribution of the chlorite is given below:

1. Of the five occurrences of late hydrothermal chlorite cited, three occupy significant positions with respect to ore (Figs. 3, 16, 17). These would seem to be particularly indicative of ore along the strike of the veins since here the chlorite occurs above oreshoots. However, the No. 3 vein occurrence might indicate that an oreshoot can occur anywhere from a few inches to 3,000 feet below observed chlorite.
2. No relation to known ore is indicated by the occurrence in the American Silver veins, and in the broad zones of their walls. This is also true of isolated zones in the hanging wall of the Yankee Girl vein on the 3,100 level of the Sunshine mine. It should be pointed out, however, that no limit on the vertical extent of chlorite above ore is known. Considering these occurrences, it would seem that the chlorite distribution pattern relative to ore-shoots lacks constancy.
3. In the Siderite vein of the Coeur d'Alene mine at points roughly 300 feet above ore, no chlorite could be found. Also, in the Chester vein of the Polaris mine on the Silver Summit tunnel level at points 2,400 feet above known ore, no chlorite was found. However, in both of these cases, oxidation of siderite had coated the drift walls and could have obscured the chlorite, although numerous samples were taken. Again, lack of constancy is indicated.
4. It is possible that limitations on sampling, due to insufficient exposures at critical points, may yield a misleading spatial distribution pattern.

Considering the favorable time of deposition and the favorability of some of the spatial distribution arguments cited, the occurrence of late chlorite in and along the walls of a carbonate-quartz vein may indicate the location of an oreshoot, either at some point down dip or perhaps within a few hundred feet along the strike from the point of observation. This *possibly* should be enhanced if the vein tends to be continuous in strike with abundant fracturing.

McConnel (17), writing of the Bunker Hill ore deposits, mentioned a pale

green mineral that occurs on joint surfaces in ore and outward up to 200 feet, forming halos around ore bodies. Sorenson (28c) mentions very late chlorite forming halos around Silver Belt ore bodies. The mineral referred to by McConnel may be chlorite. The writer observed no very late chlorite, but it is possible that the chlorite to which these men refer is a late phase of that described here.

Summary of Genetic Types of Chlorite.—Chlorite in the Coeur d'Alene mining region as a whole may be classified genetically as follows: (1) chlorite in detrital biotite, (2) diagenetic chlorite in certain strata, (3) early, hydrothermal-vein chlorite, (4) contact-metamorphic chlorite in and near the monzonitic intrusives, (5) late, hydrothermal-vein chlorite, and (6) chlorite resulting from the alteration of diabase and lamprophyre dikes. These types are listed in order of decreasing age although the latter three may be contemporaneous. Two of these types are found in the Silver Belt; i.e., chlorite of late hydrothermal origin and chlorite resulting from the alteration of basic dikes.

813 Valley National Bldg.,
Tuscon, Arizona,
Jan. 17, 1952.

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THE RELATIONSHIP BETWEEN POLARIZATION COLORS AND ROTATION PROPERTIES OF ANISOTROPIC MINERALS.

L. H. GREEN.

ABSTRACT.

The color of an anisotropic mineral under crossed nicols in reflected light is a function of the rotational properties of the mineral for various wave lengths of light.

When a mineral is placed in a position midway between the extinction positions as determined with crossed polarizer and analyser and the analyser is then rotated, a series of colors is produced. The relative dispersion of the apparent angles of rotation (DAr) for various wave lengths of light may be determined from the color sequence. Those wave lengths having the smallest angle of rotation are compensated first and the mineral grain shows the complementary color. Thus the relative dispersion of the apparent angles of rotation is the reverse of the succession of colors observed in the grain.

A basic explanation for the color of anisotropic minerals with crossed polarizer and analyser is given and the possible application of these colors to mineral identification considered.

INTRODUCTION.

In 1947 R. Galopin [1] discussed the optics of opaque minerals in reflected light and studies of polarization colors. The experimental work done by Galopin consisted of a study of a number of anisotropic minerals in plane polarized, white reflected light. Direct or orthoscopic observation was used throughout. The extinction positions of the mineral under crossed polarizer and analyser were first determined and the character of this extinction noted. The mineral was then rotated to the 45° position or midway between extinctions and the color of the grain noted. The analyser was then rotated in a direction to compensate the rotation produced by the mineral and the sequence of colors produced noted. The colors obtained were interpreted as representative of the dispersion of the mineral and Galopin believed that these colors would be of use in identification of the mineral.

Recently, a study of polarization figures by Cameron and Green [2] had led to an analysis of the dispersion effects produced by anisotropic opaque minerals and to the recognition of several properties based on dispersion characteristics. The relation of dispersion to polarization colors was not treated and the present study was undertaken for the purpose of correlating the two studies.

[1] Galopin, R., Observations sur la dispersion du plan de polarisation après réflexion normale sur les minéraux métalliques anisotropes: Schweizer. min. pet. Mitt. XXVII, pp. 190–235, 1947.

[2] Cameron, E. N., and Green, L. H., Polarization figures and rotation properties in reflected light and their application to the identification of ore minerals: Econ. Geol., vol. 45, no. 8, pp. 719–754, 1950.

PROCEDURE OF OBSERVATION AND MEASUREMENT.

Apparatus Employed.

All observations were made with a Spencer 43 AC dual purpose microscope similar to that used in previous work.[3]

The standard glass plate reflecting unit was used for all measurements in order to secure full-aperture illumination. The return passage of reflected light through this plate results in a further rotation of a ray which has undergone rotation on reflection from an anisotropic mineral. This effect will be described when it has been fully evaluated. It should be noted that this further rotation will be a function of the initial rotation, and hence while the numerical value of the rotation may require correction the order will still be correct, i.e., minerals showing slight rotation due to anisotropism will still have a rotation value less than those showing a higher rotation. As a result of this rotation, however, results obtained by direct observation of a grain using the prism illuminator will not agree with those obtained using the glass plate. Berek[4] has shown that the prism illuminator is unsuitable for this type of work because of marked variations in the azimuth of vibration and ellipticity throughout the field. With the polarizer and analyser exactly crossed, linear polarization without deviation of the azimuth of vibration is present only in a narrow centrally located strip which is parallel to the symmetry plane of the totally reflecting prism. For this reason the glass plate reflecting unit was used for all measurements.

Two Bausch and Lomb metallographic achromatic objectives were used, a 16 mm, 10 ×, 0.25 NA and a 6 mm, 37 ×, 0.65 NA. The 16 mm objective was used for direct observation and the 6 mm for conoscopic observation. Both objectives were specially selected as being free from strain, and only minor strain was obtained on testing as outlined by Cameron and Green.[5] Hence, the effects of strain should be reduced to a minimum. In addition, several other objectives were tested to determine the effects of strain on the optical system.

Red (600–700 mμ) and Blue (400–450 mμ) monochromatic filters and a standard green filter were used to determine rotation for various wave lengths. Satisfactory results were obtained with all three filters, although the small amount of light transmitted by the blue filter necessitated the use of arc lamp illumination for most measurements with this filter.

Procedure.

Crossing of Polarizer and Analyser and Orientation of Strained Objectives.—Under conoscopic observation the analyser and polarizer were crossed by observation of the polarization figure produced by an isotropic mineral.[6] This

[3] Cameron, E. N., and Green, L. H., idem, pp. 741, 742.

[4] Berek, M., Optische Messmethoden im Polarisierten Auflicht: Fortschr. der Miner., Krist., und Petrog., vol. 22, pp. 1–104, 13–14, 1937.

[5] Cameron, E. N., and Green, L. H., op. cit., p. 752.

[6] Cameron, E. N., and Green, L. H., op. cit., p. 743.

was done by rotation of the objective and the analyser until a sharp, undistorted black cross was produced.

A somewhat similar procedure is followed in direct or orthoscopic observation. An isotropic mineral is first examined and the analyser rotated until darkness is obtained. The objective is then rotated, and if a change in color or intensity of illumination is observed, the objective and analyser are rotated successively until maximum darkness is obtained.

If an anisotropic mineral is examined next it will be found that there are four extinction positions exactly 90° apart. Now if the color and brightness of the mineral are compared in two 45° positions (midway between extinctions) it will be found that any differences in color or brightness may be equalized by a slight rotation of the analyser, objective, or both. Marcasite has proven to be an extremely sensitive mineral for this test; it has been found that by careful manipulation the color and brightness in the 45° positions are exactly 90° apart.

It is believed that many of the inequalities of color and brightness observed by Galopin arose from use of a strained objective.

An interesting point observed was that using a badly strained objective which was not oriented only two extinction positions are present in a 360° rotation of the stage. This effect may occur when polarizer and analyser are exactly crossed.

Measurement.

The following measurements were made:

A. *Conoscopic Observation*
   1. The *apparent angle of rotation* (Ar) as defined by Cameron and Green[7] was determined for various wave lengths of light.
   2. The analyser was rotated in intervals, generally of one degree, in both directions from the crossed position and the nature of the figure in both 45° positions noted.

B. *Direct or Orthoscopic Observation*
   1. The apparent angle of rotation (Ar) was determined for various wave lengths of light.
   2. The analyser was rotated as under conoscopic observation and the color in both 45° positions noted.

Quantitative measurements were confined to grains showing strong anisotropism and the values obtained should be close to the maximum. Grains with lower anisotropism were examined to determine if reversals of dispersion existed.

The measurements of the *apparent angle of rotation* (Ar) were made by determining the extinction positions of the mineral with the polarizer and analyser exactly crossed and then measuring the rotations in two 45° positions 90° from one another. Measurements using polarization figures were made as described by Cameron and Green.[8] Those under direct observation

[7] Cameron, E. N., and Green, L. H., op. cit., pp. 736–737.
[8] Cameron, E. N., and Green, L. H., op. cit., pp. 742–745.

were made by determining the rotation necessary to produce a minimum of illumination or darkness.

In the measurement of rotation in direct observation it was found advisable to vary the aperture and field diaphragms until a sharp extinction was obtained. The optimum settings for the diaphragms vary, depending on the mineral, the filters used, and the source of illumination.

RESULTS OF OBSERVATION.

General Statement.

Table I shows the results of measurements of several minerals and offers a comparison of those obtained in conoscopic observation with those obtained in orthoscopic observation. It will be seen that the results are correct within the limits of accuracy in almost all measurements. The measurements were

TABLE I

OBSERVATIONS OF ANISOTROPIC MINERALS UNDER POLARIZED LIGHT

Mineral	Crystal system	Relative dispersion of reflection-rotation-DR_r	Apparent angle of rotation-A_r Blue	Green	Red	White	Relative dispersion of apparent angle of rotation-DA_r	Amount of dispersion	Figure at 45° position Analyzer and polarizer crossed	Color on rotation of the analyzer: Towards compensation	Away from compensation
Molybdenite	Hex.	x	+	+	+	11.6°± 0.5			Black isogyres on white field	0° Yellowish gray 5° Pale purple 12° Extinction 20° Light yellow gray	5° Gray 12° Light gray 20° Light gray
			+	+	+	11.6°± 0.3					
Covellite	Hex.	x rv low	7°±		8.9°±	18°±	r>v very strong	10°±	Brilliant red and blue figure; center of the field orange	0° Orange 5° Reddish orange 10° Reddish orange 20° Red 25° Purple	5° Light orange 10° 20° 25° Light yellow
		r>v	9°±		30°±	30°±	r<v very strong	21°±			
Stibnite	Orth.	x rv distinct	7.4°± 0.2	8.0°± 0.2	6.0°± 0.2	6.6°± 0.2	vv moderate	14°	Pink on concave sides of isogyres, blue fringes convex; center of the field pale blue	0° Pale blue 1° Light blue 2° Medium blue 3° Dark blue 4° Dark blue 5° Very dark blue 6° Very dark blue 7° Dark reddish brown 8° Medium reddish brown 9° Light reddish brown	1° Light blue 2° 3° 4° 5° 6° 7° 8° 9° Light gray
			7.7°± 0.3	8.7°± 0.2	6.0°± 0.2	6.9°± 0.2	vv moderate	17°			
Bismuthinite	Orth.	x vv low	+	+	+	2.0°± 0.2			Black isogyres, pale blue concave sides, orange to gray convex	0° Yellowish gray 1° Dark gray 2° Black 3° Purplish gray 4° Medium purple 5° Light purple	1° Yellowish gray 2° 3° 4° 5° Yellowish gray
			+	+	+	1.9°± 0.2					
Berthierite	Orth.	x vv low	5.5°± 0.3	5.3°± 0.2	4.3°± 0.2	5.2°± 0.2	vv moderate	12°	Black isogyres, pink concave sides, center of the field green	0° Blue-green 1° Bluish green 2° Dark bluish-green 3° Dark bluish-green 4° Dark gray 5° Dark gray 6° Dark brown 7° Pinkish brown 8° Pinkish brown	1° Light blue-green 2° 3° 4° 5° 6° 7° Very light blue green 8°
			5.4°± 0.3	5.4°± 0.2	4.3°± 0.2	4.9°± 0.2	vv moderate	11°			
Boulangerite	Orth.	x vv low	2.3°± 0.2	2.4°± 0.2	2.5°± 0.2	2.5°± 0.2	r>v	0.2°	Black isogyres, blue concave sides, yellowish gray to gray convex	0° Yellowish gray 1° Medium gray 2° Deep blue 3° Deep bluish gray 4° Medium gray 5° Medium gray 6° Light gray	1° Light yellowish gray 2° 3° 4° 5° 6° Very light gray
			+	+	+	2.5°± 0.2					
Jamesonite	Orth.	x vv low	2.6°± 0.2	2.6°± 0.2	2.7°± 0.2	2.7°± 0.2	r>v	0.1°	Black isogyres, blue concave sides, gray to pink center of the field	0° Light gray 1° Gray 2° Dark gray 3° Dark bluish gray 4° Dark bluish gray 5° Dark bluish gray 6° Gray	1° Yellowish gray 2° 3° 4° 5° Light yellowish gray
			+	+	+	2.6°± 0.2					
Bournonite	Orth.	x vv moderate	0.7°± 0.1	0.8°± 0.1	0.8°± 0.2	0.8°± 0.2	vv moderate	0.5°	Black isogyres, very narrow separation, pink concave sides bluish gray to blue convex	0° Bluish gray 1° Gray 2° 3° Light brownish gray 4° 5°	1° Bluish gray 2° 3° 4° 5° Light gray
			0.7°± 0.3	0.4°± 0.2	0.6°± 0.2	0.6°± 0.2	vv moderate	0.3°			
Marcasite	Orth.	x vv low	1.7°± 0.2	2.6°± 0.1	1.7°± 0.2	2.4°± 0.2	green>v Br	0.8°P	Black isogyres, concave sides blue to purplish center of the field bright green	0° Bright green 1° Medium green 2° Greenish gray 3° Purple 4° Purple 5° Reddish purple	1° Yellowish green 2° 3° 4° 5° Light yellowish green
			1.8°± 0.4	2.5°± 0.2	1.6°± 0.2	2.0°± 0.2	green>v Br	0.9°P			

x As measured from polarization figures. For each mineral values given in upper horizontal row were obtained from polarization figures. Values in lower horizontal row were obtained by direct (orthoscopic) measurement

+Dispersion less than errors of measurement

made on grains showing high anisotropism and should approximate maximum values. The previous results given by Cameron and Green[9] are higher for covellite and molybdenite, similar for berthierite, and lower for stibnite. These variances are due to error in selecting grains showing maximum anisotropism.

Relationship between Polarization Colors and Polarization Figures.

The color tints observed orthoscopically in a grain on rotation of the analyser when the mineral is in the 45° position may be referred directly to the color at the center of the polarization figure, although the colors may be somewhat less intense.

The following is a comparison for stibnite under direct and conoscopic observation in white light. The mineral was placed in the 45° position and the analyser rotated in intervals for a total of 8° in each direction. The negative values indicate a rotation in the direction to compensate for the rotation of the mineral and restore extinction. The positive values are in the opposite direction.

Rotation	Figure	Color of grain
+8°	A faint blue haze at the margins of the field, the remainder of the field whitish blue	Light blue
+6°	Blue isogyres at the edge of the field, the center of the field light blue	Very light blue green
+4°	Blue isogyres near the edge of the field, the center of the field pale bluish green	Robin's egg blue
+2°	Blue isogyres near the edge of the field, the center of the field blue green	Robin's egg blue
+1°	Blue isogyres pink on the concave sides, the center of the field bluish	Robin's egg blue
0°	Black isogyres, well separated, pink on the concave sides, a blue fringe on the convex and the center of the field blue	Pale blue
−1°	Black isogyres, well separated, pink on the concave sides, a blue fringe on the convex and the center of the field bluish	Light blue
−2°	As for −1°, isogyres somewhat closer	Medium blue
−3°	As for −1°, isogyres much closer and the center of the field deep blue	Dark blue
−4°	Black isogyres, almost touching, pink on the concave sides, the interval between them deep blue	Dark blue
−5°	Black isogyres, almost touching, pink on the concave sides, deep blue to black between the isogyres	Very dark blue
−6°	Black isogyres, concave sides blue green, center of the field dark brown to black	Very dark gray (brownish tint)
−7°	Black isogyres, well separated concave sides blue green, center of field reddish brown ranging outward to pink	Dark reddish brown
−8°	Black isogyres, widely separated concave sides blue green, center of field pinkish gray ranging outward to pink	Medium reddish brown

[9] Cameron, E. N., and Green, L. H., op. cit., pp. 747–748.

Dispersion.

Cameron and Green [10] describe two types of dispersion in polarization figures, the *relative dispersion of the reflection rotation* (DRr) and the *relative dispersion of the apparent angle of rotation* (DAr). Of these only the relative dispersion of the apparent angle of rotation (DAr) is readily determined under direct observation.

A. *Relative Dispersion of Reflection Rotation* (DRr).—Using polarization figures the mineral is rotated until an undistorted cross is formed under crossed nicols. The analyser is then rotated and the position and nature of the color fringes observed. The color on the concave side of the isogyre will be farthest from the center of the figure and will show the greatest rotation. Thus a figure produced in this manner showing a red fringe on the concave side and blue on the convex would be interpreted as $r > v$.

In most cases this dispersion cannot be determined using direct observation as the colors produced by rotation of the analyser are weak. One mineral, covellite, showed a bright blue on rotation of the analyser in either direction. Therefore, it was assumed that the rotation for red must be greater than blue and the correct dispersion was obtained. The other minerals studied showed weak colors which were not readily interpreted. Neither the polarization colors nor the polarization figures obtained on equal and opposite rotations of the analyser are similar, both showing slight differences in color and shade. This is believed to be due to the anisotropism of the mineral, but the effect has not been fully evaluated.

B. *Relative Dispersion of the Apparent Angle of Rotation* (DAr).—Using polarization figures the dispersion is obtained by placing the mineral in the 45° position and observing the color fringes. The color fringes are produced by the extinction of one color by the analyser, and the passage of the wave lengths which have undergone a different rotation and are not extinguished. The two colors observed in this type of dispersion are generally red and blue. Thus in the case of stibnite, where the figure shows a black isogyre with red on the concave side and blue on the convex, the dispersion (DAr) is interpreted as $v > r$.

Using direct observation the grain will be colored by the wave lengths of light which are not extinguished. When the analyser is rotated in a direction to compensate for the rotation produced by the mineral the wave lengths with the lowest rotation will be extinguished by the analyser. The grain will be colored by the wave lengths which are not extinguished. Thus this dispersion (DAr) is in the reverse order of the colors produced in a mineral grain on rotation of the analyser. In the case of stibnite this dispersion is $v > r$ since the color of the grain varies from blue to reddish as the analyser is rotated in the direction to produce compensation.

C. *Dispersions Observed by Direct Observation.*—Direct observation in white light shows the relative dispersion of the apparent angle of rotation (DAr) for covellite, stibnite, berthierite, bournonite, and marcasite. It was not shown in molybdenite, bismuthinite, jamesonite, or boulangerite, all of

[10] Cameron, E. N., and Green, L. H., op. cit., pp. 738–741.

which show zero or low dispersion in polarization figures. Marcasite and possibly stibnite show reversal of dispersion in grains of lower anisotropism. No reversals of dispersion were noted in any of the other minerals. The rotation required to produce extinction in white light was, of course, less for grains of lower anisotropism, but the colors produced on rotation of the analyser were in the same sequence, and the polarization figures all showed similar dispersion for weaker sections.

Marcasite is anomalous, having a rotation for green greater than that for red or blue. Sections of lower anisotropism show a different type of polarization figure and dispersion. Results for this mineral will be given when oriented sections have been studied.

Stibnite shows a possible reversal in grains of very weak anisotropism, but the polarization colors are not intense and may be partially obscured by internal reflection. The dispersion is as given for all except these very weak grains.

COMPARISON OF RESULTS WITH THOSE OF GALOPIN.

Taken as group the results agree very well with those of Galopin,[11] both in the colors produced on rotation of the analyser and in the interpretation of these colors. However, several points require consideration.

1. Galopin states that uniaxial minerals should show equal colors and brightness in the 45° positions but that minerals of lower symmetry should not. This is in full agreement with theory as given by Berek [12] which requires that perpendicularly incident plane polarized light be elliptically polarized by reflection from sections of minerals of lower symmetry, except for sections perpendicular to one of the three symmetry planes of an orthorhombic crystal, or to the single symmetry plane of a monoclinic crystal. This being the case, equal effects would not be expected in the two 45° positions if the reflecting surface did not lie perpendicular to a symmetry plane. However, the results obtained by a study of the colors produced on rotation by the analyser in the 45° position and of the polarization figure indicate that this asymmetry is not present in most minerals. From this observation it is concluded that the effects of ellipticity are small in most cases. Inequalities as observed by Galopin may have arisen from the use of a strained objective.

2. The statement is made that small dispersion where combined with a moderate to large rotation for white light is due to the effects of ellipticity rather than dispersion of the angle of rotation for various wave lengths. This cannot be fully evaluated at present but it has proven possible to restore extinction by rotation of the analyser in monchromatic light in all minerals studied. This would indicate that most dispersion is a function of rotation of the plane of polarization for the various wave lengths of light, or, more likely, a combination of rotational and elliptical effects.

3. The discussion of dispersion is essentially similar to that given by Cameron and Green [13] with the exception of those minerals which are colored under uncrossed nicols.

[11] Galopin, R., op. cit., pp. 220–233.
[12] Berek, M., op. cit., p. 5.
[13] Cameron, E. N., and Green, L. H., op. cit., pp. 738–741.

In this case Galopin states that the color observed in the 45° position under crossed nicols will be the complementary color to that observed under uncrossed nicols. That this is not the case may be shown by marcasite. The green observed when this mineral is at the 45° position is not complementary to the color observed with uncrossed nicols. Rather this color is produced by the combination of a high reflectivity for green and a low rotation of the plane of polarization for red and blue light as shown by the polarization figure and actual measurement. Thus the color in the 45° position with crossed nicols is related directly to the dispersion and only indirectly to the color with uncrossed nicols.

CONCLUSIONS.

The observations of polarization colors described by Galopin correlate well with the results obtained by study of polarization figures, and offer a rapid means of checking dispersions and apparent rotations produced by anisotropic minerals without reference to these figures. By use of the polarization figures the colors are shown to be directly related to the dispersion and the angle of rotation of the mineral.

Measurements of rotation made by direct observation are not as accurate as with the polarization figures and the dispersion relationships are not as clearly shown. In spite of this, it is felt that study of polarization colors produced on rotation of the analyser presents a very rapid method of comparison of minerals. It should be particularly useful to the operator who is thoroughly familiar with polarization figures.

ACKNOWLEDGEMENTS.

The author wishes to thank Dr. E. N. Cameron for bringing Galopin's article to his attention and for his helpful comments.

The author is also indebted to his wife for translating much of the original article.

UNIVERSITY OF WISCONSIN,
MADISON, WISC.,
Oct. 13, 1951.

SCIENTIFIC COMMUNICATIONS

RESEARCH, FELLOWSHIP GRANTS RENEWED BY SHELL OIL COMPANY FOR 1952–53.

The Shell Oil Company announces an increase of approximately 25 percent in grants for fellowships, stipends, and research expense allowances as part of its renewal for the 1952–53 academic year of its programs in support of higher education. A series of annual fundamental research grants initiated in 1950 will be continued at a cost of $60,000. This part of the program remains unchanged. However, the 45 graduate fellowships will receive a total of $95,000 this year, as compared with $75,000 previously. The research grants are made directly to university science departments to assist them in conducting basic research. Twelve grants of $5,000 each have been made in the fields of chemistry, chemical engineering, geology, mechanical engineering, metallurgy-corrosion, and physics. Schools receiving these awards are California Institute of Technology, Carnegie Institute of Technology, University of Chicago, Harvard, Massachusetts Institute of Technology, Yale, Stanford, and Princeton. There are no restrictions on publication of the results, nor on the way the money is spent provided it is used directly for fundamental research in the field designated. In recent years, industry has become increasingly aware of the value of extending aid for basic research, realizing that national defense and continued progress in industry are both vitally dependent on the advancements of science. The Shell program was established in recognition of the fact that although colleges and universities are well equipped to carry on such research, they are often handicapped by lack of the necessary funds. Shell's graduate fellowship program is designed to help outstanding students obtain advanced scientific degrees. It provides awards to universities in the fields of chemistry, chemical engineering, geology, geophysics, mechanical engineering, petroleum production engineering, physics, and plant science.

Students recommended by the colleges as Shell fellows receive a stipend of $1,500 for the academic year, plus payment of tuition and fees, and the school receives $400 for related research expenses of the fellow. Last year's awards were $1,200 for the stipend and $300 for research expenses. Candidates in the final year of doctorate study are given preference, but awards may be made to other graduate students. Recipients of these grants are under no obligation to Shell.

Both the fellowship and the basic research programs are administered by the Shell fellowship committee, made up of senior executives representing Shell Oil Company, Shell Chemical Corporation, Shell Development Company, and Shell Pipe Line Corporation.

DISCUSSIONS

"HOW TO WRITE GEOLOGESE."

Sir: Nicholas Vanserg's letter on Geologese [1] contains many cogent points, developed with well-sustained Merrillian irony. I hope I shall not seem inappreciative of the former if, in the following constructive comments, I do not emulate the latter.

"Geologese" may not previously have appeared in print, but it has been used in written discussions of Survey manuscripts; and so has "Surveyese." So, too, has "headlinese," which is a better name than "journalese" for the long compound modifier. Journalists have to write much better than most geologists—otherwise they could never make a living out of journalism—and journalists confine headlinese to headlines, whereas geologists put it into the body of the text. An example from a newspaper headline is "D. C. May Become Quake Study Hub"— i.e., a center for investigating earthquakes. One from the body of a geological manuscript is "half an inch to 3 inch thick layers," and one from a printed review is "the in vertical cross section roughly horseshoe-shaped barrier." A constructive measure of defense against these Teutonisms would be to enforce the unit-modifier rule of hyphenation, like this: "half-an-inch-to-3-inch-thick layers" and "the in-vertical-cross-section-roughly-horse-shoe-shaped barrier." Such *reductio-ad-adsurdum* hyphen-chains might act as a lucky-horseshoe barrier to in-text-rather-than-in-headlines headlinese-use.

Mr. Vanserg would have been more constructive if he had shown—even at the cost of spoiling a joke—that the dog-legs on page 221 could be straightened out by inserting a few commas—after "rocks" in the first example, after "decreases" in the second, and after "chalcopyrite" and "vestiges" in the third. If the commas were omitted by the writers they should have been put in by the editors. And by the way, in Mr. Vanserg's otherwise well-punctuated letter, two commas that would have been helpful are omitted—one in line 3 of page 222 (after "references") and one near the middle of the same page (after "Language"). I wonder why?

Curious uses of certain words are more frequent in Geologese than in English. Common examples are "postulate" for "assume," and "comprise" for "constitute." I have even seen "is comprised of." Webster (which, to give the devil his due, distinguishes between "postulate" and "assume") now puts these uses of "comprise" on an equal footing with its use in a sense allied to "include." The two meanings are about as compatible as "inside" and "outside," and etymology shows that "comprise" is a cousin of "include." A

[1] Vanserg, Nicholas, How to write Geologese: Econ. Geol., vol. 47, no. 2, pp. 220–223, 1952.

rarer item is "disinterest," for "apathy," which I have found in an address by a geologist-editor, but nowhere else except in Webster, which approves that use. "Uninterest" would surely be better English, since, in modern usage, an apathetic person is uninterested, whereas only an unselfish person is disinterested. Yet "uninterest" is not Webster at all! I wonder why.[2]

FRANK C. CALKINS

U. S. GEOLOGICAL SURVEY,
WASHINGTON 25, D. C.,
May 12, 1952.

[2] That phrase *will* keep coming in, perhaps because this is the week of the Pick and Hammer Show.

REVIEWS

A Land. By JACQUETTA HAWKES. Pp. 238; pls. 16; maps 4. Random House, Inc., New York, 1951. Price, $3.75.

When day's work is done and one likes to sit back and relax and grab a novel or a storybook, one looks for something that will hold one's interest and be relaxing at the same time. Plunging into a book on geology, under whatever guise it may be, is a "busman's holiday," but when geology is combined with poetry that is another matter.

A Land is a study of Britain from the Precambrian till 1949. In vivid colors Britain's past is traced through geologic eras and periods, and through the cultural and political achievements of its inhabitants. The author is a scientist and poet, she has taught archeology and anthropology at Cambridge, and her husband is professor of archeology at Oxford. Her previous books include both works on archeology and poetry.

The book presents a short lecture course on geology, archeology, and cultural history. In Creation she touches on formation of the earth, weathering, sedimentation, preservation of fossils, volcanism, igneous, sedimentary, and metamorphic rocks, genesis of ore minerals, tectonic upheavals, and meteorites. In Recollection she discusses historical geology, British stratigraphy, and paleontology. She explains evolution and loves it all. "The trilobite was an aristocrat in the Cambrian; but the lobster today—whether it eats man at the seafloor or man eats it in his own world of air it has gone too far."

Apparently unrelated subjects are skilfully woven into one piece and dramatically presented. During continental Devonian times, she recounts, "when an island sea dried up, there must have been a horrible flapping and floundering, a dull rattling of horny armor before they (ostracoderms) suffocated and the bodies of untellable shoals were buried, later to form a dense mass of fossilized remains."

Poems are cited as a backbone to an already poetic portrayal. "The bosom of the landscape lifts and falls with its own leaden tide" in geomorphic cycles, while in the story of the evolution of the cephalopods the reader is told, "learn of the little Nautilus to sail, spread the thin oar and catch the driving gale."

British stratigraphy is discussed in some detail and makes fascinating reading, particularly to those who, like the reviewer, know the Wrekin, Longmynd, Cader Idris, and other type localities she describes.

Her chapter "Digression on Rocks, Soils and Men" is perhaps the most enchanting description of the economic geology of building and ornamental stone yet presented. She discusses the different rock types and notes where they have been used in famous castles and cathedrals, quaint villages and tombstones, churches and public buildings, and the sculptures of Henry Moore.

Mrs. Hawkes writes in the first person and present tense which strikes a harsh note when Cambrian seas are described. However, her style is fluent, picturesque, even beautiful, occasionally verging on the obscure and becoming philosopher's doodling. She sees modern man "enjoying a unity with trilobites," yet "the nature of this unity cannot be stated."

Her facts on the whole are accurate and have been checked by K. P. Oakley, the British geologist. A few controversial statements are offered as dogmatic facts. Whether the story of the earth began with granite is very debatable, and that in the reptiles for the first time the male had to seek and take the female is perhaps misleading. "The rocks of Charnwood Forest, Leicestershire, are hard and without memory of life"; yet fossils, perhaps both true and dubious, have been recorded in that area by Bennett, Lapworth, and the reviewer. Not "all igneous intrusions have an aureole of metamorphic rocks," as Mrs. Hawkes states: and that "liquids and gases released by the heat" of the "intrusion of fiery rocks" bring about ore deposits is not convincing. However, such inconsistencies are lost sight of in the beauty of the language and the progress of the story.

The author has a keen sense of humor and occasionally takes it out on the Americans. Flints are things that "bring us dollars by their sale to those curiously atavistic organizations, the flint and lock gun clubs of the United States." Whether the 90 foot diplodocus ever lived in Britain is not known, "it is not surprising that it throve in America. Why do not Americans put up a life-size monument to the all-time record in life size?"

Excellent photographs of fossils, landscapes, geologic structures, paintings of Henry Moore, and other British artists lend further color to the book. Plates depicting oceans and land areas in Lower Carboniferous, Jurassic, Eocene, and Pleistocene times conclude the volume.

This book in its own way provides some of the most interesting and readable material on geology, particularly British geology, and archeology to appear in many years.

GERALD M. FRIEDMAN.

UNIVERSITY OF CINCINNATI,
CINCINNATI, OHIO,
March 3, 1952.

The Barker Index of Crystals. Vol. I, Pts. 1 and 2. By M. W. PORTER and R. C. SPILLER. Pp. 1500; tbls. W. Heffer and Sons, Ltd., Cambridge, 1951. Price, £6; Pt. 1 separately, 30s.

The enormous task of calculating thousands of classification angles, assembling these and other determinative data (refractive indices, density, melting point), and properly indexing all, in addition to rewriting complete crystal descriptions of so many substances, is a remarkable accomplishment. The patient and thorough work of the authors and the devotion of the sponsoring Committee constitute a fine tribute to Dr. Barker. The Barker Index of Crystals is not only a work of reference for professional crystallographers, but also an important tool for chemical analysis. Its publication permits the identification of an unknown substance through the measurement of a few angles on one of its crystals. In many cases the identification is unequivocable; in others, an observation of the density, the refractive indices, or the melting point, or a simple qualitative chemical test, will distinguish between the few alternatives allowed after assuming a possible experimental error of one-half degree in the measurement of the angle. The speed of determination by means of these tables will generally be comparable with that of determination by any other physical property; the reliability of the conclusion will be known, and usually good.

Part 1 of the present volume I contains first an elementary but sufficient explanation for non-crystallographers, followed by a complete technical introduction; then follow the determinative tables for tetragonal, hexagonal and trigonal,

and orthorhombic crystals, comprising separate tables based upon crystallographic classification angles, refractive indices, densities, and melting points of some 3,000 substances; finally, alphabetical indices in English and German facilitate ready reference to Part 2.

Part 2 of this volume includes complete, serially numbered, crystallographic descriptions of tetragonal, hexagonal and trigonal, and orthorhombic crystals. The arrangement of the latter is that of Groth's Chemische Kristallographie (Vols. 1–5, 1906–1919), to which credit is given for many of the data herein catalogued. The inclusion of references to the ASTM card file of powder X-ray diffraction data is most highly to be commended.

The second volume of the Barker index is planned for publication in 1953, to cover monoclinic crystals; a third and final one, devoted to triclinic crystals, will be published later.

The introductory matter has been typeset; the tables are photolithographed from typewritten copy to eliminate one step at which errors might originate. Unfortunately, the pages are not numbered, except in the introduction, but colored sheets facilitate finding the beginning of each major section.

Nearly all analysts will profit from at least some familiarity with this method. The Index is the first summary of the crystallographic properties of most known substances since Groth's; the inclusion of determinative tables makes it much more useful.

HORACE WINCHELL

YALE UNIVERSITY,
NEW HAVEN, CONN.,
March 3, 1952.

Theoretical Petrology. By TOM E. W. BARTH. Pp. 387; figs. 146. John Wiley & Sons, Inc., New York, 1952. Price, $6.50.

This interesting book by an outstanding petrologist covers the present status of knowledge of the petrology of igneous, metamorphic, and sedimentary rocks. It is an exact scientific study of rock-making processes. It interprets the new mass of data that have arisen from world-wide experimental work, geophysical and geochemical laboratories, and from individual researches.

It is broad in its scope. Under Part I, Physics and Chemistry of the Earth, is covered the origin, heat, and strength of the earth, its composition, its concentric shells, and geochemical cycles. Part II considers the sedimentary rocks, their formation, differentiation, chemistry of sedimentation, and special rocks. Part III, the meat of the book, deals with Igneous Rocks. First there is a section on descriptive classifications describing mineralogical classifications, chemical composition, and petrochemical calculations and classifications. A second section is entitled "Physical Chemistry of the Minerals" which covers the formation of the various rock-making minerals. A third section is called "Magmas and their Locales." This goes into melts, immiscibility, phase diagrams, and other features of magmas. The last section of Part III is entitled "Rocks as Products of Defined Processes." Here the author surveys differentiation, rock series, basalts, orogenic rock series, and granitization. Part IV, on Metamorphic Rocks, leads the reader into the various complications of metamorphism and metamorphic products.

The book is a thorough and comprehensive coverage of the subject indicated by the title, and is well illustrated by drawings and diagrams. It is an advanced book that should prove to be the standard reference for all specialists in petrology.

The Dynamics of Faulting, and Dyke Formation with Applications to Britain, 2nd Edit. By E. M. ANDERSON. Pp. 206; figs. 39. Oliver and Boyd, Edinburgh, 1951. Price, 22/6.

This edition follows its predecessor after a nine-year interval and also expounds a theory of faulting based upon Navier's principle. The early chapters deal with the dynamics of faulting and of dike formation. The next three chapters treat of examples in Great Britain. The 7th chapter deals with crustal dynamic problems, particularly related to stress. The last chapter on conclusions gives an historical summary and general inferences. A few new references have been added but very little additional text matter appears to have been added.

Handbook of Gem Identification, 3rd Edit. BY RICHARD T. LIDDICOAT, JR. Pp. 315; figs. 116. Gemological Institute of America, Los Angeles, Calif., 1951.

This third edition differs somewhat from its predecessors. The chief additions are recently developed testing instruments, synthetics, spot methods of refractive index determinations, and new tables.

After description of the properties of gemstones, the main part of the book deals with tests and procedures followed in the identification of gemstones, which are grouped according to color. Instruments essential to gem testing are described in detail, and it is shown how to differentiate imitation stones from real ones. Thirty pages of valuable tables follow the identifications.

The book will be useful to all students of mineralogy and particularly to amateur mineralogists.

Magic Oil, Servant of the World. BY ALFRED M. LEESTON. Pp. 213. Juan Pablos Books, Dallas, Texas, 1951. Price, $3.75.

This interesting book is written by a teacher, Ph.D. in international law and economics, who is also assistant in economic and foreign work to E. L. De Golyer. He therefore has had opportunity to learn about foreign oil situations.

The central theme of the book is that petroleum is a builder of peace and a defender in war. The author attempts to show that oil is a positive force in crushing totalitarian tendencies toward expansion, and that a study of oil developments is a refutation of critics of the oil industry. His survey aims to show, by presenting the industry in action, the accomplishments of the oil industry in this country and abroad, and to prove that its tremendous success is the outcome of skillful, efficient, and alert management operating under a system of competitive free enterprise. This the author does by presenting studies, in case history fashion, of the oil industries in the United States, Middle East, Far East, Russia, Europe, and the Americas. He points out the economic conditions of the countries, their history, the peoples, the problems faced, and the accomplishments. A selected but good bibliography follows.

The reader is presented with good factual data written interestingly and should be disabused of much misinformation that gets into the press and literature.

Introduction to Geophysical Prospecting. BY MILTON B. DOBRIN. Pp. 419; figs. 264; tbls. 20. McGraw-Hill Book Co., Inc., New York, N. Y., 1952. Price, $7.00.

This book will be welcomed by all geologists, particularly by those whose knowledge of physics and mathematics is either not advanced or rusty. No mathematics beyond trigonometry is required for its reading. The book arose from notes pre-

pared for a course in "Survey of Geophysical Prospecting," which the author taught for two years to graduate students and seniors in mining engineering. The book is, therefore, written at a fairly elementary level for geologists and engineers engaged in exploration for fuels or minerals. Nevertheless, the fundamentals and techniques are thoroughly covered, and emphasis is placed upon gravity, magnetic, and seismic techniques.

The twenty-one chapters deal first with gravity, giving fundamental physical principles, isostacy, instruments, measurements, reductions, and interpretation. The next four chapters treat of magnetic principles, instruments, earth magnetism, measurements and interpretation, and the air-borne magnetometer.. This is followed by four chapters on seismic principles, earthquakes, wave propagation, instruments, and refraction and reflection methods. Then come single chapters on electrical prospecting methods, prospecting for radioactive minerals, integration of geophysical methods, geophysical well logging, radio position locations, and current research in geophysical exploration and the relation of geophysics to geology.

The scope of the book and the method of treatment will have an appeal to all geologists and engineers interested in geophysical prospecting, and to teachers who desire a book that treats of the subject without extended mathematical treatment.

Water. By Sir Cyril S. Fox. Pp. 148; figs. 4; pls. 25. The Philosophical Library, Inc., New York, N. Y., 1952. Price, $8.75.

This short book, printed in Great Britain, is the first to be published as one of a series on water supply being prepared by Technical Press, Ltd. This volume is intended to provide the reader with an outline of its science of water, both theoretical and practical.

The book is divided into three parts. Part I is an elementary treatment of I, The Constitution of Water, II, The Distribution of Water, and III, The Circulation of Water. Chapters 2 and 3 cover the material customarily included in textbooks of physical geology or geography. Part II, The Work Done by Water, also with three chapters, is again simple physical geology with subject matter similar to that covered in all elementary textbooks of geology. The chapters are headed, Erosion of the Land Surface, The Action of Underground Water, and The Deposition of Sediments. Part III, The Utilization of Water, is divided into General Considerations, Water Supply Engineering, and Concluding Remarks. These three chapters cover the elements of hydrology, except the last one of four pages, which contains some new material on radioactive water in Bikini Atoll, water rights, and national aspect of water supply. All of the text material is nicely presented in simple language.

The four figures appear quite inadequate to illustrate the text material. Fourteen of the twenty-five plates are United States illustrations of unknown source, except for those credited to the National Geographic Society.

Little of the subject matter appears to be new, and much of it is drawn from older references. The book suffers by comparison with eight other books dealing with water that have appeared in the last four years. One wonders also why the price should be $8.75 for an under illustrated book of 148 pages!

Dana's Manual of Mineralogy, 16th Edit. Revised by Cornelius S. Hurlbut, Jr. Pp. 530; figs. 471. John Wiley & Sons, Inc., New York, N. Y., 1952. Price, $6.00.

This new edition of a classical book that has gone through 15 former editions, exceeds its predecessor in size by some fifty pages. These additional pages result

in part from new sections, and in part from the addition of new material to bring the book thoroughly up to date.

The book starts off with a new chapter, "Mineralogy," dealing with the history of mineralogy and the nature and applications of mineralogy and crystallography. Its purpose is to orient the student before he is plunged into the complications of crystallography. It is a valuable addition and an improvement. Another new section on "Crystal Chemistry" has been inserted under the chapter on "Chemical Mineralogy." This permits the introduction of the new material that has arisen regarding the nature of the solid state arising from x-ray data and crystal chemistry in general.

One also notes that the "Occurrence and Association of Minerals," which treats of the rocks and rock-forming minerals, and veins and vein-minerals, has been lifted out of its former subsections under "Descriptive Mineralogy" and placed under a separate Chapter 6. It is perhaps unfortunate that all of the kinds of metallic mineral deposits have been listed under "Veins," and "lateral secretion" is included as a vein-forming process—usages that will make the miner and the economic geologist shake their heads.

The new subsection on "Crystal Chemistry" is well presented in simple language using common illustrations. In this, the reasons are given for the classification now adopted in the book. The whole chapter on "Chemical Mineralogy" has been greatly improved.

The chapter of "Mineral Uses" has been brought up to date with the incorporation of many of the new uses for minerals that have developed since the previous edition. The incorporation of exact statistics of production of the different metals, and their prices, is perhaps not wise since they become out of date between the time of writing and the appearance of the book, particularly since the last figures were for the year 1948. For example, aluminum production for 1948 is given as 1,265,000 tons whereas shortly it will be more than double that amount; the price of nickel given as 40 cents a pound is now 56½, and of mercury given as $76 a flask is now $225!

The book as a whole is a fine improvement in presentation and modernization over its predecessor and Professor Hurlbut and John Wiley and Sons are to be congratulated for this final successor to a large series of editions.

Les Pegmatites—Las Pegmatites Granitiques, Vol. I, Partie Prèliminaire, Chaps. 1–10; Vol. II, Partie Descriptive, Chaps. 11–18; Vol. III, Partie Générale, Chaps. 19–25. By the late A. E. Fersman. Translated from the Russian edition of 1931 by Belgian and Russian geologists under the direction of R. du Trieu de Terdonck and J. Thoreau. Pp. 675, plus illus., mimeographed form. University of Louvain, Louvain, Belgium, 1951. Price, 900 Belgian francs ($18.00) postpaid.

The subject matter of this monumental work by Fersman, of which only extracts have been published in German and English, has been translated from the Russian into French by a corps of Belgian and Russian geologists in order to make it more available to geologists of the world. The appendices, excepting the bibliography, have not been translated. The book was originally published by the Academy of Sciences of the U.S.S.R. in Leningrad. This French translation and the valuable bibliography now makes this monumental work available to all who can read French.

Although much has been learned in regard to pegmatites since the appearance of Fersman's work, nevertheless the original work contains much fundamental material, a great body of research and factual information. All who are interested in

pegmatites will be indebted to these two gentlemen. Copies may be obtained through money orders addressed to Professor Thoreau, 10 Rue St. Michel, Louvain, Belgium.

Festschrift Zum Siebzigsten Geburtstag Von Rudolf Richter. EDITED BY HERTA SCHMIDT AND GERHAD SOLLE. Pp. 336; many figs.; pls. 54; maps 5. Abhand. Sencken. Natur. Gesell., Frankfurt Am Main, 1951.

This large memorial volume to Professor Rudolf Richter was written by 11 of his former scholars. The contents are: Hansjoachim Lippert—Zur Gesteins- und Lägerstattenbildung in Roteisenstein-Gruben des östlichen Dill-Gebietes; Wilhelm Simon—Untersuchungen im Paläozoikum von Sevilla (Sierra Morena, Spanien); Scott Simpson—Some solved and unsolved Problems of the Stratigraphy of the Scott Simpson—Some Solved and Unsolved Problems of the Stratigraphy of the Marine Devonian in Great Britain; Ernst-Eberhard Hotz and Karl Krömmelbein —Das "Antoniusbusch-Profil" im Devon der Rohrer Mulde (Eifel); Richard Kräusel—Der tertiäre "Riesenahorn" *Banisteriaecarpum* nov. gen. Die Systematische Stellung von *Acer giganteum* und *Acer otopterix* Göppert; Wilhelm Kegel —Diskordanz der Schalen bei Pectiniden und Pteriiden; Erich Triebel—Einige stratigraphisch wertvolle Ostracoden aus dem höheren Dogger Deutschlands; Herta Schmidt—Das stropheodonte Schloss der Brachiopoden; Gerhard Solle—Geologie, Paläomorphologie und Hydrologie der Main-Ebene östlich von Frankfurt am Main; Wilhelm Schäfer—Fossilisations-Bedingungen brachyurer Krebse; and Helmut Bartenstein and Erich Brand—Mikropaläontologische Untersuchungen zur Stratigraphie des nordwestdeutschen Valendis.

The text material is printed in double columns on pages 8 x 12 inches in size. The various articles are well illustrated with plates, charts, and figures. A pocket contains three large maps. The list of contents above indicates the variety and scope of the volume. It is an outstanding memorial to an outstanding teacher.

BOOKS RECEIVED.

FRANK G. LESURE.

U. S. Geological Survey—Washington, D. C., 1951.

Prof. Paper 232. Paleocene Foraminifera of the Gulf Coastal Region of the United States and Adjacent Areas. JOSEPH A. CUSHMAN. Pp. 75; tbls. 4; pls. 24. Price, $1.75. *Descriptions and illustrations of smaller foraminifera from the Gulf Coastal Region, Cuba, Central America, Haiti, and Trinidad.*

Prof. Paper 233-A. Fresh-Water Mollusks of Cretaceous Age from Montana and Wyoming. TENG-CHIEN YEN. Pp. 20; pls. 2. Price, 45 cts. *Part 1, A fluviatile fauna from the Kootenai formation near Harlowton, Montana; Part 2, An Upper Cretaceous fauna from the Leeds Creek area, Lincoln County, Wyoming.*

Prof. Paper 233-B. Molluscan Fauna of the Morrison Formation. TENG-CHIEN YEN. Pp. 30; fig. 1; pls. 6. Price, 65 cts. *Illustrations and descriptions of pelecypods and gastropods preceded by a summary of the stratigraphy by John B. Reeside, Jr.*

Prof. Paper 233-D. Devonian and Mississippian Rocks of Central Arizona. JOHN W. HUDDLE AND ERNEST DOBROVOLNY. Pp. 45; figs. 19; pls. 3. Price, 65 cts. *Stratigraphic studies, in the central part of the state, as the basis for postulating stratigraphy and petroleum possibilities in northeastern Arizona.*

Prof. Paper 236-A. Foraminifera from the Arctic Slope of Alaska. HELEN TAPPAN. Pp. 20; figs. 2; pls. 5. Price, 50 cts. *Description and illustrations of the first Triassic foraminiferal fauna discovered in the Western Hemisphere.*

Prof. Paper 239. Scaphitoid cephalopods of the Colorado group. W. A. COBBAN. Pp. 42; figs. 4; pls. 21. Price, $1.50. *Evolution of scaphites and related genera, with descriptions and illustrations of new species and a new genus from Western Interior United States.*

Prof. Paper 240-A. Foraminifera of the Lodo Formation Central California. B. M. ISRAELSKY. Pp. 29; figs. 2; pls. 10. Price, $1.25. *A study of the foraminiferal fauna of a Paleocene and Eocene formation of scientific and economic importance.*

Bull. 969-F. Geology of the Tungsten, Antimony and Gold Deposits Near Stibnite, Idaho. JOHN R. COOPER. Pp. 46; figs. 4; pls. 7. Price, $2.50. *Three stages of Tertiary mineralization: gold followed by scheelite followed by stibnite.*

Bull. 970. Geology and Ore Deposits of the Upper Blue River Area, Summit County, Colorado. QUENTIN D. SINGEWALD. Pp. 74; figs. 17; pls. 7. Price, $1.75. *Two mineralogical areas described: western area contains high temperature gold, tungsten, iron ores, and minor molybdenum and low temperature lead, zinc, and silver deposits; eastern area contains oxidized lead and zinc ores, and some gold and silver.*

Bull. 971. Geology and Ore Deposits of the Castle Dome Area, Gila County Arizona. N. P. PETERSON, C. M. GILBERT, AND G. L. QUICK. Pp. 134; figs. 9; tbls. 4; pls. 9. Price, $2.25. *Zonally arranged disseminated pyrite-chalcopyrite mineralization modified by supergene enrichment.*

Bull. 978-C. Gold Placer Deposits of the Pioneer District, Montana. J. T. PARDEE. Pp. 30; figs. 10; pl. 1. Price, 45 cts. *A geologic study of the historic diggings along Gold Creek. The gold is found in alluvium along lower Gold Creek, in patches of terrace gravel, and in glacial drift.*

Bull. 978-E. The Wallapai Mining District, Cerbat Mountains, Mohave County, Arizona. MCCLELLAND G. DINGS. Pp. 40; fig. 1; tbls. 2; pls. 2. Price, $1.00. *Primary sphalerite, galena, and chalcopyrite occurs in pyritic quartz veins and lodes formed at intermediate depths.*

Bull. 979-A. Manganese Deposits of Western Utah. MAX D. CRITTENDEN, JR. Pp. 62; figs. 2; tbls. 22; pl. 1. Price, 50 cts. *Descriptions of individual deposits of syngenetic and epigenetic deposits.*

Bull. 980. A Cooperative Investigation of Precision and Accuracy in Chemical, Spectrochemical and Modal Analysis of Silicate Rocks. H. W. FAIRBAIRN. Pp. 71; figs. 10; tbls. 27; pl. 1. Price, 35 cts. *Part 1, Preparation and distribution of the samples; Part 2, Results of chemical analysis of samples of granite and diabase, by William G. Schlecht and Rollin E. Stevens; Part 3, Spectrochemical analysis of major constituent elements in minerals and rocks, by W. H. Dennen, L. H. Ahrens, and H. W. Fairbairn; Part 4, Spectrochemical analysis of some of the rarer elements in the granite and diabase samples, by L. H. Ahrens; Part 5, Modal analyses of the test rocks, by Felix Chayes; Part 6, Summary of results.*

Bull. 981-C. Geophysical Abstracts 146 July–September, 1951. MARY C. RABBITT AND S. T. VESSELOWSKY. Pp. 61. Price, 20 cts. *Abstracts Nos. 12891–13092.*

Bull. 984. Geologic Reconnaissance of the Mineral Deposits of Thailand. GLEN F. BROWN, SAMAN BURAVAS, JUMCHET CHARALJAVANAPHET, NITIPAT JALICHANDRA, WILLIAM D. JOHNSTON, JR., VIJA SRESTHAPUTRA, AND GEORGE C. TAYLOR, JR. Pp. 183; figs. 38; tbls. 4; pls. 20. Price, $2.50. *Brief discussion of physiography and geology. Detailed descriptions of many deposits of metallic and non-metallic mineral deposits.*

Water-Supply Paper 1000. Geology and Ground-Water Resources of the Santa Maria Valley Area, California. G. F. WORTS, JR. Pp. 169; figs. 9; tbls. 16; pls. 6. Price, $1.75.

Water-Supply Paper 1107. Geology and Water Resources of the Santa Ynez River Basin, Santa Barbara County, California. J. E. UPSON AND H. G. THOMASSON, JR. Pp. 194; figs. 23; tbls. 30; pls. 7. Price, $1.00.

Water-Supply Paper 1108. Geology and Ground-Water Resources of the South-Coast Basins of Santa Barbara County, California. J. E. UPSON. Pp. 144; figs. 11; tbls. 17; pls. 9. Price, $1.50.

Water-Supply Paper 1110-B. Ground-Water in the Cuyama Valley, California. J. E. UPSON AND G. F. WORTS, JR. Pp. 60; figs. 2; tbls. 10; pls. 5. Price, 65 cts.

Water-Supply 1134-A. Flood of August 4–5, 1943 in Central West Virginia. H. M. ERSKINE. Pp. 57; figs. 25; tbls. 9; pl. 1. Price, 40 cts.

Water-Supply Paper 1106. Public Water Supplies in Western Texas. W. L. BROADHURST, R. W. SUNDSTROM, AND D. E. WEAVER. Pp. 168; pl. 1. Price, 50 cts.

CIRC. 175. The Carnotite Prospects of the Craven Canyon Area, Fall River County, South Dakota. L. R. PAGE AND J. A. REDDEN. Pp. 18; figs. 2; tbls. 2; pl. 1. *Widespread, small low-grade deposits in base of Lakota sandstone.*

U. S. Atomic Energy Commission—Oak Ridge, Tennessee, 1951–52.

RMO-697. Review of Airborne Radioactivity Survey Techniques in the Colorado Plateau. J. A. TAVELLI. Pp. 12. Price, 10 cts.

RMO–838. Analytical Procedure for the Determination of Thorium. R. KRONSTADT AND ALLAN R. EBERLE. Pp. 9. Price, 10 cts.

Deformation, Metamorphism, and Mineralization in Gypsum-Anhydrite Cap Rock, Sulphur Salt Dome, Louisiana. MARCUS I. GOLDMAN. Pp. 168; figs. 5; pls. 64. Geol. Soc. America Mem. 50, New York, 1952. *Detailed petrographic descriptions from study of diamond drill core through entire cap rock. Cap rock formed as result of solution of salt by groundwater. Formation of gypsum from anhydrite and flowage phenomena described. Origin of sulphur attributed to action of hydrocarbons on calcium sulphate. Many excellent photomicrographs illustrate phenomena described.*

Measurement of Geologic Time. COMMITTEE MEMBERS. Pp. 140. National Academy of Sciences—National Research Council 212, Washington, D. C., 1952. Price, $1.00. *Contains an annotated bibliography of articles related to the measurement of geologic time.*

Sources of Iron Ore in Asia. JOSEPH F. HARRINGTON AND BENJAMIN M. PAGE. Pp. 176; figs. 59; tbls. 11. General Headquarter Supreme Commander for the Allied Powers, Economic and Scientific Section, Natural Resources Division, Rept. 154, Tokyo, 1952. *Preliminary report of regional picture of known important iron ore deposits in East Asia.*

Proceedings of the United Nations Scientific Conference on the Conservation and Utilization of Resources, Vol. II, Mineral Resources. Pp. 303. United Nations Department of Economic Affairs, New York, 1951. Price, $3.00. *Selected papers by leading authorities on the following topics are presented with discussions: Mineral supplies and their measurement; The outlook for future discovery; Increasing Mineral Resources by discovery; Conservation in Mining and Milling; Conservation in Manufacture; Conservation by corrosion control; Conservation by substitution; Inorganic fertilizers in conservation; List of contributors to Mineral Resources Section.*

Introduction to Geology. E. B. BRANSON AND W. A. TARR, 3rd Edit.; C. C. BRANSON AND W. D. KELLER (WITH MRS. W. A. TARR). Pp. 492; figs. 434. McGraw-Hill Book Co., Inc., New York, 1952. Price, $5.50. *This third edition has undergone some, but not drastic, revision. The chief changes are the introduction of later scientific and statistical material, and some new illustrations including airplane views. Physical and historical geology are included.*

World Population and Future Resources. EDITED BY PAUL K. HATT. Pp. 262; figs. 5. American Book Company, New York, N. Y., 1951. Price, $3.50. *Four parts: The population factor, food resources, material resources of industry, energy resources. Includes papers on mineral exploitation and world problems, mineral resources of ocean, coal resources, and others.*

The American Economy. A. F. YOUNGSON BROWN. Pp. 208. Library Publishers, New York, 1952. Price, $4.75. *Brief, comprehensive account of economic development of United States from Civil War to 1940.*

Electrolytic Manganese and Its Alloys. REGINALD D. DEAN. Pp. 257, figs. 100; tbls. 68. The Ronald Press Company, New York, N. Y., 1952. Price, $12.00. *Record of progress of electrolytic manganese production and development of its uses since 1936. Chapter 1, Production and Properties of Electrolytic Manganese; Chapter 2, Non-ferrous Alloys of Electrolytic Manganese; Chapter 3, Ferrous Alloys of Electrolytic Manganese.*

Plane Table Mapping. JULIAN W. LOW. Pp. 365; figs. 148; tbls. 8. Harper & Brothers, New York, N. Y., 1952. Price, $5.00. *A practical and clearly written pocket manual slanted to the needs of the beginner. Mapping methods, care and adjustment of instruments, use of aerial photographs, drafting of maps, etc. A valuable text for teacher, student, and field geologist.*

The Mines Magazine. Denver, Colo., March, 1952. Price, 50 cts. *Special number featuring the Colorado Mining Convention. Includes papers on uranium, production, structural geology, base metal controls and production, non-metallics, and others.*

Études Tectoniques Et Magmatiques Au Maniema (Congo Belge). H. VAN EYKEREN. Pp. 94; figs. 17. Amsterdam, 1951. *A study of stratigraphy, tectonics, magmatic activity, and gold, tin, and tantalite-columbite mineralization of an area in the Belgian Congo northwest of Lake Tanganyika.*

Cavernicolous Pselaphid Beetles of Alabama and Tennessee, with Observations on the Taxonomy of the Family. ORLANDO PARK. Pp. 107; figs. 18; tbls. 4. Alabama Geol. Survey Mus. Paper 31, University, Alabama, 1951.

California Division of Mines—San Francisco, 1952.

Special Rept. 17. Suggestions for Exploration at New Almaden Quicksilver Mine, California. EDGAR H. BAILEY. Pp. 4; pl. 1. Price, 25 cts. *Future exploration based on knowledge of shape of serpentine bodies around which ore is localized.*

Special Rept. 18. Geology of the Whittier-La Habra Area, Los Angeles County, California. CHARLES J. KUNDERT. Pp. 22; figs. 19; pls. 3. Price, 50 cts.

Illinois Geological Survey—Urbana, 1952.

Bull. 76. Geology of the Fluorspar Deposits of Illinois. J. MARVIN WELLER, ROBERT M. GROGAN, AND FRANK E. TIPPIE WITH CONTRIBUTIONS BY L. E. WORKMAN AND A. H. SUTTON. Pp. 147; figs. 25; tbls. 4; pls. 7. *A description of the geology, the exploration, mining and milling, and the mining districts. Fluorspar occurs in fissure veins, bedded replacements deposits, and residual concentrations.*

Rept. Inv. 159. Pleistocene Geology of the Danville Region. HARMON E. EVELAND. Pp. 32; figs. 14; pl. 1.

Rept. Inv. 161. Preliminary Report on the Variations in Differential Thermal Curves of Low-Iron Dolomites. DONALD L. GRAF. Pp. 27; figs. 8; tbls. 3.

Indiana Department of Conservation—Bloomington, 1951–52.

Bull. 6. Geology and Mineral Deposits of the Jasonville Quadrangle, Indiana. CHARLES E. WIER. Pp. 34; figs. 6; tbls. 8; pls. 6. Price, $1.00. *Part of new study and appraisal of Indiana coal resources.*

Directory Ser. 2. Directory of Coal Producers in Indiana. CHARLES E. WIER. Pp. 45; figs. 2; pl. 1. Price, 25 cts.

Kansas University and Geological Survey—Lawrence, 1952.

Bull. 96, Pt. 2. Coal Resources of the Cretaceous System (Dakota Formation) in Central Kansas. WALTER H. SCHOEWE. Pp. 107; figs. 23; pls. 6. *Description of geographic distribution, stratigraphic position, thickness, contact rocks, and physical and chemical characters of Dakota formation coals.*

Bull. 96, Pt. 3. Oil Shale in Kansas. RUSSELL T. RUNNELS, ROBERT O. KULSTAD, CLINTON MCDUFFEE, AND JOHN A. SCHLEICHER. Pp. 27; figs. 2; pls. 3. *Results of testing 37 locations.*

Bull. 96, Pt. 4. Minor Elements in Kansas Salt. RUSSELL T. RUNNELS, ALBERT C. REED, AND JOHN A. SCHLEICHER. Pp. 15; tbls. 5; pl. 1. *Spectrochemical analyses for trace elements in mine run salt, raw brine, and prepared salt products.*

The Lakes of Minnesota, Their Origin and Classification. JAMES H. ZUMBERGE. Pp. 99; figs. 48; pls. 2. Minnesota Geol. Survey Bull. 35, Minneapolis, 1952. *Systematic treatment of geologic factors involved in lake formation with emphasis on the effects of glaciation.*

Additional Analyses of Brines from Ohio. RAYMOND E. LAMBORN. Pp. 56; map 1. Ohio Geol. Survey, Dept. Nat. Resources, Rept. Inv. 11, Columbus, 1952. *Analyses of 42 additional brines.*

University of Texas Publications—Austin, 1952.

**Geol. Quad. Maps. Spring Creek Quadrangle, Gillespie County; Morris Ranch Quadrangle, Gillespie and Kerr Counties; Blowout Quadrangle, Gillespie and Llano Counties; Willow City Quadrangle, Gillespie and Llano Counties; North Grape Creek Quadrangle, Blanco and Gillespie Counties; Palo Alto Creek Quadrangle, Gillespie County; Cain City Quadrangle, Gillespie and Kendall Counties; Gold Quadrangle, Gillespie County; Hilltop Quadrangle, Gillespie, Llano, and Mason Counties; Bear Creek Quadrangle, Gillespie, Kerr, and Kendall Counties; Squaw Creek Quadrangle, Gillespie and Mason Counties; Live Oak Creek Quadrangle, Gillespie County; Crabapple Creek Quadrangle, Gillespie and Llano Counties; and Stonewall Quadrangle, Gillespie and Kendall Counties—*all in Texas.* VIRGIL E. BARNES. *Colored geologic maps, scale 1:31,680 accompanied by brief descriptions of the geology of the different areas.*

A Study of Soils and Land Forms of the Chesapeake Bay Margins. G. F. CARTER AND V. P. SOKOLOFF. Pp. 37; fig. 1; tbl. 1. The Johns Hopkins University, Baltimore, Maryland, 1951. *Progress report.*

Canada Department of Mines—Ottawa, 1951–52.

Mem. 260. Geology and Coal Deposits of Minto and Chipman Map-Areas, New Brunswick. J. E. MULLER. Pp. 40; tbls. 2; pls. 5. Price, 75 cts. *Distribution, reserves, character, analysis, and thickness of Minto coal seam.*

Mem. 262. Ashcroft Map-Area, British Columbia. S. DUFFELL AND K. C. MCTAGGART. Pp. 122; figs. 3; pls. 5. Price, 75 cts. *Describes late Paleozoic to Tertiary formations, their relation to coast intrusions, structure, and mineral deposits.*

Mem. Ser. 117. Preliminary Report on Coated Lightweight Concrete Aggregate from Canadian Clays and Shales, Pt. 1, Alberta. Pp. 68; figs. 4; map 1. *Results of test work on samples from deposits near well populated areas.*

Annual Rept. Pp. 99. Price, 50 cts.

Prospecting for Uranium in Canada. OFFICERS OF THE RADIOACTIVITY DIVISION. Pp. 167; figs. 2; tbls. 3. Price, 50 cts. *Favorable areas for prospecting, methods and instruments used, descriptions of minerals, methods of sampling, information on government regulations, and other valuable information.*

Ontario Department of Mines—Toronto, 1952.

60th Annual Rept., Vol. LX, Pt. II, 1951. Mines of Ontario in 1950. COMPILED BY M. READE. Pp. 111.

Prel. Rept. 1952–2. The Geology of the Lac Aux Sables—Shakwa Lake Area, Districts of Algoma and Sudbury, Ontario. H. W. SHEERAN. Pp. 4; pl. 1. *Predominantly granitic rocks cut by diabase dikes. Minor radioactivity.*

Prel. Rept. 1952–3. Lumby Lake Area, Districts of Kenora and Rainy River. R. S. WOOLVERTON. Pp. 3; pl. 1.

Quebec Department of Mines—Quebec, 1951–52.

Geol. Rept. 32. Pontgravé-Bergeronnes Area, Saguenay County. E. W. GREIG. Pp. 27; figs. 7; pl. 1; map 1. *Descriptions of pegmatite deposits in which mica is most important mineral.*

Geol. Rept. 34. Normetal Mine Area, Abitibi-West County. CARL TOLMAN. Pp. 34; tbls. 2; pls. 4; maps 2.

Prel. Rept. 264. Bethoulat Lake Area. E. R. W. NEALE. Pp. 13; pl. 1; map 1. *A northward extension of the Huron-Mistassini fault zone is described. Northeast-striking rocks of the east side (h.w.) resemble those of the Grenville subprovince; east-striking rocks of the west side (f.w.) resemble those of the Timiskaming subprovince. The possibility of an ilmenite deposit within the anorthosite-pyroxene granite series of the hanging wall is mentioned.*

The Mining Industry of the Province of Quebec in 1950. Pp. 87; fig. 1; tbls. 38; pls. 2. *Annual report.*

List of the Principal Operators and Owners of Mines and Quarries in the Province of Quebec. Pp. 83.

Report of the Geological Survey Board for the Year 1950. Pp. 28. Dept. Scientific and Industrial Research. His Majesty's Stationery Office, London, 1951. Price, 1s.3d.

Geological Survey Department—Kuching, Sarawak—H. M. Stationery Office, London, 1951–52.

Bull. 1. Geology of the Colony of North Borneo. MAX REINHARD AND EDUARD WENK. Pp. 160; figs. 29; tbls. 11; pls. 30. Price, £2 12s.6d. *Detailed descriptions of Tertiary, sedimentary, and igneous rocks, and Pre-Tertiary volcanic, sedimentary, and igneous rocks based on extensive work by the authors and geologists of Shell Oil Company. Contains much valuable information that is now made available for the first time.*

Rept. for 1950. F. H. FITCH. Pp. 99; figs. 6; tbls. 22; pls. 7. Price, Straits $2 or 4s.8d. *Preliminary descriptions of oil, gold, coal, antimony; phosphates and non-metallic deposits.*

The Natural Resources of Sarawak. F. W. ROE. Pp. 38; figs. 29. Price, Straits $0.50 or 1s.2d.

The Diamondiferous Gravels of Lichtenburg. ALEX L. DU TOIT. Pp. 58; figs. 7; pls. 9. Geol. Survey of South Africa, Dept. of Mines, Mem. 44, Pretoria, 1951. Price, 5s. *Diamondiferous gravels trapped in sinks in Precambrian dolomite, now form high areas due to solution of surrounding carbonate rocks.*

The Geological Society of South Africa—Johannesburg, 1950–51.

Alex L. du Toit Mem. Lectures 2. Metamorphism and Granitisation. H. H. READ. Pp. 27. *Further discussion of problems of granitization. Author concludes, "It may be that it is only by the grace of granitization that we have continents to live on."*

Trans. Vol. LIII. Vertical Mineral Variation in the Great Dyke of Southern Rhodesia. H. H. HESS. Pp. 7; figs. 4; tbl. 1.

Minerales No. 39. Pp. 168. Inst. ing. Chile Rev., Santiago, 1951. *Includes papers on copper in Chile and geology of uranium deposits.*

Ministerio de Minas e Hidrocarburos—Caracas, Venezuela, 1951–52.

Bol. 69. Actividades Petroleras. Pp. 16.

Bol. 70. Actividades Petroleras. Pp. 15.

Vol. 1, No. 2. Boletin de Geologia. Pp. 84; figs. 16; tbls. 14; pls. 9. *Papers on economic geology, general geology, and paleontology in Venezuela.*

Encore Á Propos de la Genèse des Orthopyroxènes. DJALMA GUIMARÃES. Pp. 19; figs. 5; pls. 3. Inst. de Tech. Industrial, Avulso 11, Belo Horizonte, 1952. *Traces transformation of clinopyroxene to orthopyroxene.*

Boletin Do Int 2. Pp. 78. Ministério do Trabalho, Indústria e Comércio, Rio de Janeiro, Brasil, 1951.

Relatório de 1950. Pp. 245; figs. 24; many illus. Conselho Nacional do Petróleo, Rio de Janeiro, Brasil, 1951.

Sumario. Pp 178. Boletin de la Escuela Nacional de Ingenieros, Ser. III, Tomo XXIV, Lima, Peru, 1951. *Includes a paper on the structure of the earth by J. A. Broggi.*

Geologia do Couto Mineiro da Panasqueira. DÉCIO THADEU. Pp. 64; figs. 10; pls. 12. Direccao Geral de Minas e Servicos Geológicos, Lisboa, 1951.

Congo Belge. A. JAMOTTE. Pp. 29. Association des Services Geologiques Africains, Bruxelle, 1951. *Bibliography of geologic publications on Belgian Congo, 1945–1949.*

Les Richesses Minerales du Congo Belge. ED. POLINARD. Pp. 99; figs. 139. Editions Bieleveld, Bruxelles, 1951. *Origin and utilization of the diamond, tin, gold, copper, manganese, and sedimentary deposits.*

Géologie Dauphinoise. MAURICE GIGNOUX AND LÉON MORET. Pp. 384; figs. 92; maps 3. Masson et Cie, Paris, 1952. Price, 1650 fr. *This second edition has been enlarged, the number of figures increased, and the bibliography added to.*

Géologie Appliquée et Prospection Minière. Pp. 212; figs. 43; pls. 8. L'Association des Ingénieurs Géologues de L'Université de Nancy, Bull. 1–2–3, Tome III, Nancy, 1951. Contribution a l'Étude des Gites de Tungstène Français. Maurice Weppe. *Concludes tungsten deposits result of accidental manifestations of metamorphism rather than having formed by hydrothermal solutions.*

Les Gites d'Étain et de Tungstène de la Région d'Oulmes (Maroc Central) —Étude Géologique, Pétrographique et Métallogénique. HENRI TERMIER. Pp. 328; figs. 40; pls. 27; 2 colored maps. Notes et Mémoires du Service Géologique, Rabat, 1950. Price, 1200 fr. *Tin and tungsten deposits of the Oulmes area, Central Morocco. Extensive descriptions of the sedimentary rocks, granitic intrusives, contact metamorphisms, and mineralization.*

Les Terrains Sédimentaires de la Région de Morondava. VICTOR HOURCQ. Pp. 105; figs. 23; pl. 1. Service des Mines de Madagascar Fasc. XX, Paris, 1950. *Stratigraphy and structural geology of Morondava.*

Comptes Rendus de la Société Géologique de Finlande No. XXIV—Helsinki, 1951.

Extrait. Über Einige in Ostfinnland Angetroffene Kieserzgeschiebe. MARTTI SAKSELA. Pp. 19; figs. 10; pl. 1. *Description of a copper deposit in East Finland.*

Extrait. Späthydrothermale Bildungen im Kieserz von Otravaara, Ostfinnland. MARTTI SAKSELA. Pp. 7; figs. 2; tbl. 1. *Description and origin of sphalerite and galena deposits of Otravaara.*

Extrait. Zur Mineralogie und Entstehung der Pitkäranta-Erze. MARTTI SAKSELA. Pp. 50; figs. 20; pls. 3. *Mineralogy and origin of the Pitkäranta ores.*

Around Pitkäranta. PENTTI ESKOLA. Pp. 90; figs. 30; tbls. 4; pls. 5. Annales Acad. Sci. Fenn. Ser. A III Geologica-Geographica, Helsinki, 1951. *In two parts: under the heading, Dome district of Pitkärantas are described structure, petrology, the problem of primordial granite, pegmatites, and potash feldspar. Concludes that "perhaps contrary to common belief orthoclase is the low temperature phase of potash feldspar. Under the heading the ore district of Pitkäranta, are described late, black andradite and ores in cavernous skarn, serpentization of dolomite, ore deposits in dolomite, and their origin.*

SCIENTIFIC NOTES AND NEWS

P. C. BENEDICT, geologist for the Newmont Mining Corp., is now located in New York. He had been in Johannesburg, South Africa for the firm.

The DALLAS GEOPHYSICAL SOCIETY, a local section of the Society of Exploration Geophysicists, sponsored a symposium on electromagnetic wave propagation in the earth at Southern Methodist University in Dallas on February 12.

HAROLD M. BANNERMAN, assistant chief geologist of the U. S. Geological Survey, left Washington, D. C., in January to begin work on the resources of Puerto Rico as a part of the Puerto Rico Cooperative Minerals Investigations studies.

The GEOLOGY AND MINERALOGY SECTION OF THE MICHIGAN ACADEMY OF SCIENCE, ARTS AND LETTERS, held its annual meeting at the University of Michigan, Ann Arbor, Michigan, on April 11. Papers were presented at two sessions; a morning meeting devoted to varied subjects and an afternoon meeting consisting entirely of papers on the iron deposits of Michigan and allied problems in Michigan Precambrian geology.

EARL M. IRVING has been made mining consultant to the Philippines Government. This work will be carried on as a part of his U. S. Geological Survey duties.

N. M. SHORT died in late March at his home in North Dakota.

JOHN V. BEALL, editor of Mining Engineering, New York, N. Y., has been appointed manager of publications for the American Institute of Mining and Metallurgical Engineers.

W. D. JOHNSTON, JR., chief of foreign geology branch of the U. S. Geological Survey, has been named a Foreign Member of the Brazilian Academy of Science.

DR. TAKEO WATANABE, professor of Economic Geology at Tokyo University has announced the publication of *Mining Geology*, the journal of the newly organized Society of Mining Geologists of Japan.

P. H. SEVENSMA has been appointed senior mine geologist at the Sullivan Mine, Consolidated Mining and Smelting Company of Canada, Ltd., at Kimberley, B. C.

DR. LEROY SCHARON, associate professor of geology at Washington University in St. Louis, Missouri, was elected chairman of the Mining, Geology, and Geophysics Division of the AIME at the Institute's annual meeting in New York, February 18–21. He now becomes a director ex officio of the Institute during his year of service.

P. E. CLOUD, JR., chief of the Paleontology and Stratigraphy Branch of the U. S. Geological Survey, has been appointed as the twelfth member of the Pacific Science Board of the National Research Council, the appointment becomes effective on July 1, 1952.

JOHN OLSON has joined the geological department of the Inland Steel Company and will be stationed at Iron River, Michigan, where he will devote his time to Inland's Menominee Range properties.

PHILIP W. CHASE, formerly manager of explorations for the Oliver Iron Mining Division, in Duluth, Minnesota, has been transferred to the United States Steel Corporation's raw materials department in Pittsburgh.

HARRY V. WARREN of the department of mining at the University of British Columbia was recently elected president of the British Columbia and Yukon Chamber of Mines, succeeding M. M. O'Brien.

EDWIN B. ECKEL, chief of the engineering geology branch of the U. S. Geological Survey, left Washington, D. C., in February for Asuncion, Paraguay, on a six months' Point Four assignment. In cooperation with geologists of the Paraguayan Government, he will make a reconnaissance survey of mineral resources of Paraguay to determine which deposits would justify detailed investigations and development. Mr. Eckel will also assist in the organization of a National Geological Survey in Paraguay and help in the selection of men to be brought to the United States for additional training before becoming attached to the new organization.

D. F. KIDD of Vancouver, British Columbia, has been elected president of the Canadian Institute of Mining and Metallurgy at its annual meeting in Ottawa.

The SOCIETY OF EXPLORATION GEOPHYSICISTS, HOUSTON SECTION, held its annual Gulf Coast regional meeting May 29–30, 1952.

E. N. CAMERON recently returned from a month's study of tungsten deposits of French Morocco.

JOSÉ RAYMUNDO DE ANDRADE RAMOS of the Division of Geology and Mineralogy of Brazil arrived in Washington, D. C., in February for a period of one year in-service training with the U. S. Geological Survey in stratigraphy and paleontology.

M. N. S. RAO and S. N. SENGUPTA of India arrived in February for a period of one year's in-service training in geophysics with the U. S. Geological Survey. They are assistant geophysicists with the Geological Survey of India.

The INDUSTRIAL MINERALS DIVISION of the AIME will hold its fall regional meeting in Chicago, September 3–6, to participate in the Centennial of Engineering Celebration. Field trips will take place September 3 and 4, followed by technical sessions dealing with survey of industrial minerals locally produced or imported for use in the Chicago area, and featuring description of methods used in exploration for developing and production of groundwater for industry.

R. M. LEGGETTE announces the formation of a partnership with M. L. BRASHEARS under the name of Leggette and Brashears consulting groundwater geologists, at 551 Fifth Avenue, New York.

The first annual meeting of the PERMIAN BASIN GEOPHYSICAL SOCIETY was held at Midland, Texas, on May 17 at which 8 technical papers were presented. The Permian Basin Geophysical Society is a local section of the Society of Exploration Geophysicists with members scattered throughout West Texas and New Mexico. Officers are Lester H. Johnson, President; George A. Grimm, First Vice President; Paul C. Reed, Second Vice President; L. Decker Dawson, Jr., Secretary; and R. M. Nugent, Treasurer.

The COLORADO SCHOOL OF MINES EIGHTEENTH ANNUAL ENGINEERS' DAY attracted nearly 1,500 people for the celebration on April 18–19. 61 representatives showed equipment at this year's exhibit. The 2-day session allowed Colorado School of Mines students to exchange ideas with top industrialists. The principal

speaker at the affair was Dr. James Boyd, who blasted the trend toward centralization in the federal government. Speakers other than Boyd were: C. E. Ridell, George R. Downs, Milton B. Dobrin, S. P. Warren, Paul D. Torrey, James D. Forrester, Malcolm P. Gever, and Elmer Gammeter.

The WYOMING GEOLOGICAL ASSOCIATION will hold its Seventh Annual Field Conference August 1, 2, and 3, 1952, with headquarters at Thermopolis. The Mesaverde, Frontier, Phosphoria, and Tensleep formations will receive particular attention. Areas to be visited include the north flank of the Owl Creek Mountains (type section of Embar), the Win River Canyon (north portion), Mahogany Butte, Tensleep Canyon and the Kirby Creek, Lake Creek, Black Mountain, Manderson and Nowood anticlines. The route of one of the field trips will also carry the caravan past the sulphur plant north of Worland. The general chairman is Andrew G. Alpha of the General Petroleum Corp.

J. DONALD ALLAN, chief geologist of the Province of Manitoba, Mines Branch, has left the government and is now geologist with the California Standard Co., Calgary, Alberta.

HENRY LIGGETT HOSMER has been made geologist, Morococha Div., Cerro de Pasco Corp. Mr. Hosmer had been assistant geologist.

CLIFTON W. LIVINSTON, head of the mining department at the Colorado School of Mines, has resigned to become president and director of research for the Mining Research Corporation.

PAUL SHAFFER, after 14 years experience in the Philippines as geologist with the Benguet Consolidated Mining Company and the Atok-Big Wedge Mining Company, both at Baguio has become a general consulting geologist with headquarters in Manila.

C. EDWARD JACOB, faculty member of the University of Utah has accepted a six-month position with the Mutual Security Agency to serve as a consulting groundwater geologist in Formosa.

WILLIAM L. MCDONALD, geologist in the Great Slave Lake area of Canada, has been engaged by the Tungsten Corp. of Canada, Ltd., to thoroughly examine all underground workings at the Outpost Islands tungsten mine.

JOHN H. MOSES has left Peru after 16 years with Cerro de Pasco Corp. During the last 3 years he was their chief geologist. He is now with the Reynolds Mining Company at Little Rock, Arkansas, in the United States.

JAMES DOUGLAS, who has been serving as Assistant Deputy Administrator of the D.M.P.A., has accepted the post of Deputy Director of the agency's new Region 3 office in London where he becomes assistant to Brig. General Thomas B. Wilson, who as D. of Region 3, will have charge of D.M.P.A. activities in Free Europe, Middle East, and North Africa.

THE GEOLOGICAL SURVEY announces that 8 preliminary aeromagnetic maps, presenting results of aeromagnetic surveys in Arizona were placed in open file in Tucson, Ariz., and Washington, D. C.

The U. S. Atomic Energy Commission needs experienced geologists in its Division of Raw Materials in both domestic and foreign positions. Salaries—$5,060 (GS-9), $5,940 (GS-11), $7,040 (GS-12), and $8,360 (GS-13), depending on experience. Minimum experience three years. Civil Service status not required. Those interested should write to U. S. Atomic Energy Commission, 70

Columbus Avenue, New York 23, N. Y., Attention Mr. Robert D. Nininger, Division of Raw Materials.

GEORGE ARONIS, geologist with the Ministry of National Economy in Athens, Greece, and GEORGE MARINOS, assistant professor of mineralogy and petrology at the University of Athens, came to Washington, D. C., in March under the in-service trainee program sponsored by the Mutual Security Agency. They will spend six months visiting several U. S. Geological Survey field projects concerned with economic geology and hydrology to become familiar with the type of work being done and the methods and techniques being used.

The National Science Foundation has appointed RALPH A. MORGEN, director of the Engineering and Industrial Experiment Station of the University of Florida, to direct the Engineering Research Support Program in the engineering sciences.

NORWOOD B. MELCHER, mineral economist and commodity specialist with the Bureau of Mines for more than 10 years and widely experienced in the ferrous metals and alloys field, has been appointed Chief of the Ferrous Metals and Alloys Branch of the Bureau's Minerals Division. Mr. Melcher is married, has 4 children, and lives at 11 Albermarle Street, Chevy Chase, Md.

DAVID A. ANDREWS, geologist with the Foreign Geology Branch of the U. S. Geological Survey, returned to Washington, D. C., late in April after a 3½-month assignment in Thailand acting as consultant on the Thai Coal Program. He also visited Formosa and the Philippines for consultations regarding their future mineral programs.

The SOCIETY OF EXPLORATION GEOPHYSICISTS held their 5th annual meeting in Houston, Texas, May 29 and 30. About 1,000 members attended and 20 papers were presented in the 2-day session. Curtis H. Johnson's presidential address was "Progress in Oil Finding."

ROBERT F. MEHL, head of the department of metallurgical engineering at Carnegie Tech, delivered the commencement address at the Colorado School of Mines 78th annual exercies May 29, which stressed the need for research in the fields of geology, prospecting, and metallurgy.

The DMPA has appointed the following to be chiefs of 4 branches of the Foreign Expansion Division: CARREL B. LARSEN, South American Branch; C. A. FREDELL, North and Central American Branch; JAMES D. MCCLINTOCK, European and African Branch; RUSSELL C. FLEMING, Far Eastern and Asian Branch.

CHARLES S. PICHAMUTHUS, director of the Mysore Geological Survey, India, arrived in the United States early in April under the Department of State's Leader-Specialist program. During his 6-months' stay in the United States he will visit U. S. Geological Survey field offices, universities, and private companies to become acquainted with the different types of geologic work being done in this country.

CYRIL KNIGHT, a consulting geologist in Toronto, Canada, is now located in Port Credit, Ontario, Canada.

D. W. LINDGREN, formerly geologist with Oliver Iron Mining Co., Duluth, Minn., is now manager for West Indies Mining Corp., Santurce, Puerto Rico.

H. D. KEISER, formerly a member of the Geological Survey, has transferred to the USBM as a commodity-industry analyst in the Rare and Precious Metals Branch.